DATA COLLECTION SURVEY ON CURRENT SITUATION
OF
THE PROJECT FOR IMPROVEMENT OF COASTAL
FISHERIES DEVELOPMENT
IN SAINT LUCIA

FINAL REPORT

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JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

ECOH CORPORATION

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Abbreviations

A	Al_3O_3	Alumina Aluminum Oxide
B	BW	Breakwater
C	CaO	Calcium Oxide
D	DCA	Development Control Authority
	DWG	Drawings
E	E	East
	EC$	Eastern Caribbean Dollars
	EIA	Environmental Impact Assessment
	ENE	East North East
F	FAD	Fish Aggregating Device
	Fe_2O_3	Iron (III) Oxide
	FDDA	Four-Dimensional Data Assimilation
	FNL	Final
G	GPS	Global Positioning System
H	HACCP	Hazard Analysis Critical Control Point
J	JICA	Japan International Cooperation Agency
	JMA	Japan Meteorological Agency
	JRA-55	Japanese Re-Analysis
M	MSL	Mean Sea Level
N	N	North
	NCAR	National Center for Atmospheric Research
	NCEP	National Centers for Environmental Prediction
	NOAA	National Oceanic and Atmospheric Administration
U	USGS	United States Geological Survey
S	S	South
	SiO_2	Silicon Dioxide
	SFMC	Saint Lucia Fish Marketing Corporation
	SQX	Semi Quantitative analysis X-ray
	SSE	South-South East
	SSW	South-South West
W	W	West
	WA	Wraparound
	WRF	Weather Research and Forecasting
	WW3	Wave Watch III

■ Location Map of Saint Lucia and Project Site

Location of Saint Lucia

Location of Project Site

Chapter 1　Background and purpose of this project

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Saint Lucia, which is located in eastern Caribbean, is a volcanic island with 22.4 kilometers in East and West, 42.3 kilometers in North and South and has an area of 616 square kilometers with exclusive economic zone of 8,000 square kilometers and continental shelf of 176 square kilometers. Fishery industry in this country is one of the most important industries. There are about 1,700 tons of landing per year. And fish such as dolphinfish, tunas, marlins in the offshore and bottom fish such as shellfish and crustaceans in the shelf waters can be caught. These are valuable sources of protein for citizens, and they also supply precious ingredients to the tourism industry of the country. Approximately 2,600 people, about 1.5% of the population, are engaged in the fishing industry.

Japan has been conducting various cooperation for the fishing industry over the past 20 years and has contributed to the development of the fishery industry in the country. The catch is landed at 17 locations in the island, but 10 main landing sites take more than 80% of the total landing volume. All of them are developed by Japanese grant through the past 20 years.

The Choiseul fishing port, which is located in the Southwestern part of the country, is also one of the fishing ports developed by Japanese grant. As of 2012, 54 vessels and 181 fishermen were registered and the port was used as one of the country’s major fishing ports. At this fishing port, the deposition phenomenon was confirmed in 2002, and monitoring survey for three years had been conducted by a consultant who was in charge of the construction supervision. Based on the monitoring results, the consultant made a proposal to the government of Saint Lucia that maintenance dredging was the most appropriate as a deposition countermeasure in 2006.

However, the government of Saint Lucia decided to extend the breakwater to lower the frequency of dredging works as much as possible. Also, the government of Saint Lucia itself implemented the extension of the additional breakwater in 2007.

Fishing vessels cannot smoothly enter and moor in Choiseul fishing port due to deposition at the port entrance. It results in hindering the mooring and landing of fishing vessels. The government of Saint Lucia has taken measures such as intermittent dredging works at the port entrance in addition to extending additional breakwater until now. But the expenditure required for frequent dredging works is a heavy burden for the country.

Based on those circumstances, the government of Saint Lucia has sent a request for cooperation to Japan through the Embassy of Japan in Trinidad and Tobago for consideration of deposition countermeasures. In response to this request, JICA cooperated with the Ministry of Foreign Affairs of Japan to conduct survey for confirming current status, and understood the current situation by hearing the opinions and needs of fishermen including related persons from government of Saint Lucia. Based on this results, JICA decided to conduct the data collection survey to confirm concreate countermeasures to solve the deposition in Choiseul fishing port.

Based on the above, this project has aimed to confirm the existence of highly feasible countermeasure for the function recovery and improvement of Choiseul fishing port against deposition and to collect and organize information for preparatory survey on refurbishment of the port.

Chapter 2　Operation and maintenance management system

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2.1 General conditions and issues of fishing industry in Saint Lucia

Figure 2-1 shows transition of volume and value of fish landings from 2007 to 2016 in Saint Lucia. 1,509 ton, the volume in 2007, increased to 1,810 ton in 2008. Promotion measures by Department of Fisheries such as introduction of FAD probably contributed to the increase. Then, the volume is kept from 1,600 to 1,800 ton. EC$19,560 thousand, the value of landings in 2007 increased to EC$23,629 thousand in 2008. Then, the value of landings has slightly increased to EC$27,083 thousand in 2016.

Figure 2-2 shows the volume of landings by fish species in 2016. Offshore large pelagic fish such as tunas and dolphinfish account for 54.9% of the whole volume of landings. Landings of demersal fish like snappers and coral fish including conchs and lobsters are small. Figure 2-3 and 2-4 show the volume and value of fish landings by site. Vieux Fort is the largest in its volume of landings with 530 ton (30.6%), followed by 360 ton (20.8%) in Dennery. Volume of landings in Vieux Fort and Dennery accounts for 51.4% of the whole. The same can be said of value of landings. Value of landings in Vieux Fort is EC$7,973 thousand (29.4%) and the largest, and Dennery follows with its value of landings of EC$5,472 thousand (20.2%). Value of landings of Vieux Fort and Dennery occupies 49.6% of the whole.

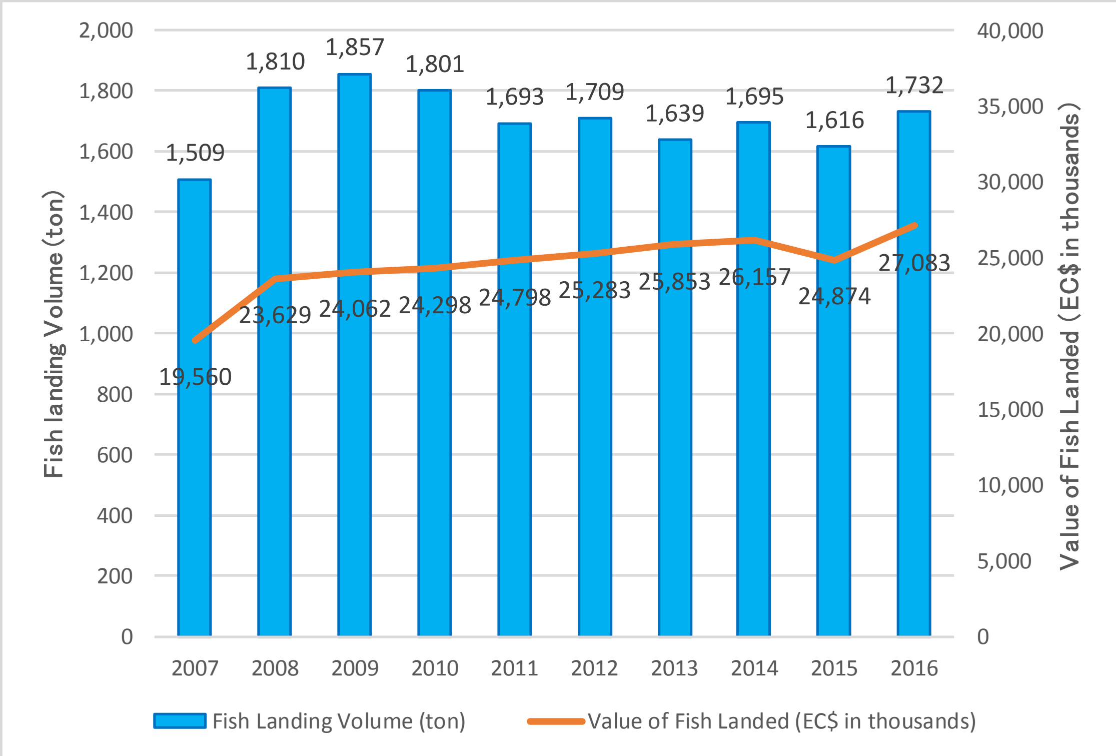
Table 2-1 shows the number of registered fishing vessels by site and type. The total number of registered fishing vessels is 822. The number of registered fishing vessels is 207 (25.2%) in Vieux Fort, 85 (10.3%) in Castries and 72 (8.8%) in Soufriere. Regarding the boat types, the number of pirogue type is 642 (78.1%) followed by canoes with its number of 72 (8.8%).Table 2-2 shows the number of registered fishers in 2016. There are 2,775 registered fishers (1,706 full-time fishers, and 1,069 part-time fishers), and 290 distributors and others. Vieux Fort is the largest having 555 persons (20.0%), followed by Castries with 324 persons (11.7%) and Dennery with 309 persons (11.1%).

The characteristic of fisheries sector in Saint Lucia is imbalance between fish supply and demand. Fish supply during peak season from January to March becomes excessive, but the supply shortage occurs except for the peak season. Offshore pelagic fish are found in Caribbean Sea side, and such fish are landed tremendously by trawlers during January to March under the calm sea conditions. However, during the low season, especially from June to December under the severe sea conditions, operation days and time decrease, and resultantly volume of landing becomes considerably small.

The Department of Fisheries so far has purchased the excess fish during the peak season and developed the facilities to freeze and preserve such fish to distribute during the low season. Sustainable use of resources is the important issue by operational cost decrease thanks to installation of FAD inducing a school of fish near the shore, and decreasing fishing pressure for demersal fish and coral fish such as conchs and lobsters which are all easy to be depleted.

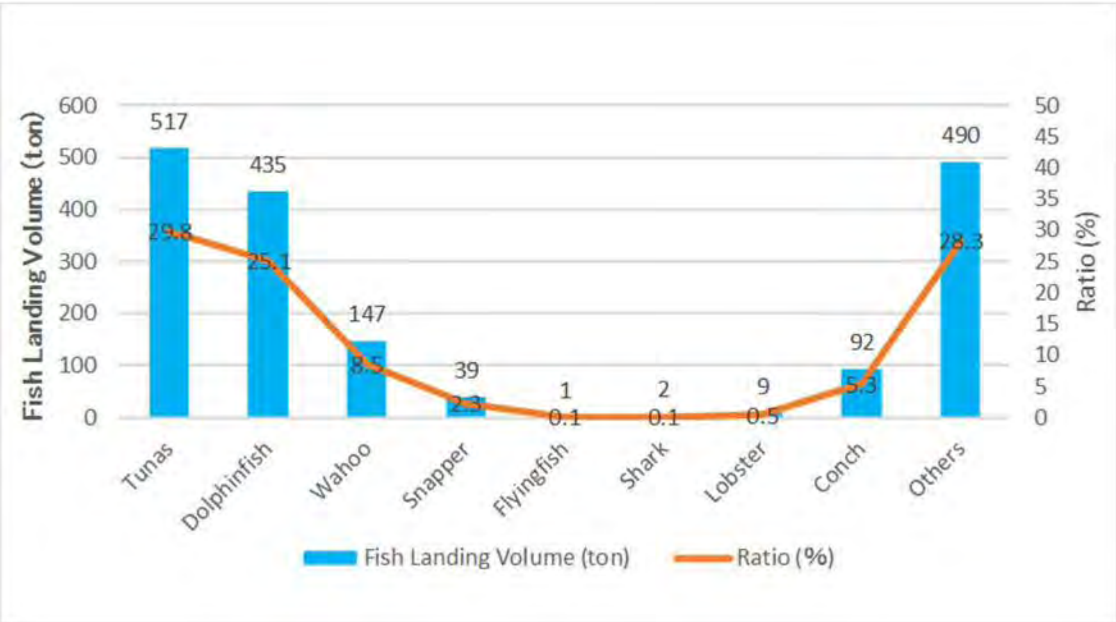
Additionally, most of the registered fishers are vessel owners and captains, and just a few crews are registered because of some reasons such as they do not feel the necessity of registration. It is one of the administrative problems for the Department of Fisheries since comprehension of the number of fishing vessels and fishers is essential to consider the effective fisheries promotion policy.

As for the characteristics of fishing vessels and fishing methods in Saint Lucia, there are almost no pirogue with cabin, trawling is mainly carried out even to catch the large pelagic fish and longline fishing is seldom used. The operation is on a daily basis and 20 to 30 miles offshore is the operation limit since the vessels do not have cabins. Improvement of fishing vessels and introduction of alternative fishing methods are also the future challenges.



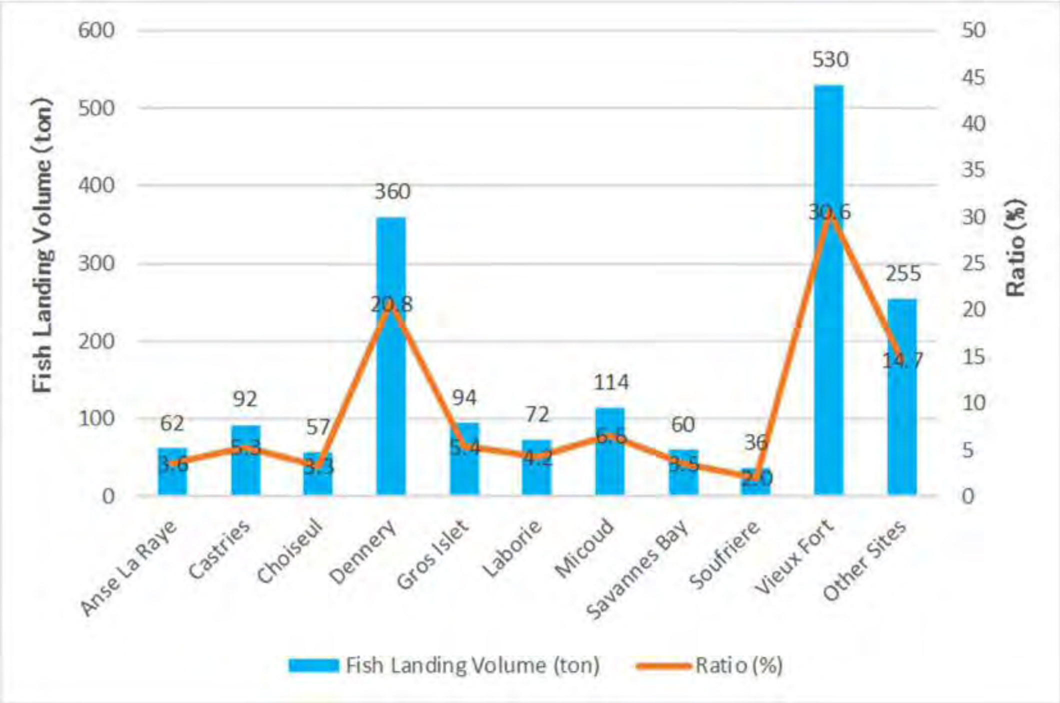
(Source: Statistics of Department of Fisheries, 2017)

Figure 2-1 Transition of volume and value of fish landings from 2007 to 2016



(Source: Statistics of Department of Fisheries, 2017)

Figure 2-2 Volume of landings by fish species in 2016



(Source: Statistics of Department of Fisheries, 2017)

Figure 2-3 Volume of fish landings by site in 2016

(Source: Statistics of Department of Fisheries, 2017)

Figure 2-4 Value of fish landings by site in 2016

Table 2-1 The number of registered fishing vessels by site and type in 2016

SITE	CANOE	PIROGUE	TRANSOM	SHALOOP	WHALER	LONGLINER	OTHER	TOTAL
ANSE LA RAYE	4	20	0	0	0	0	0	**24**
BANANNES	3	30	13	0	0	2	1	**49**
CANARIES	18	9	4	3	1	0	0	**35**
CASTRIES	1	59	18	2	1	4	0	**85**
CHOISEUL	12	39	0	3	0	0	0	**54**
CUL DE SAC	0	4	4	1	0	0	0	**9**
DENNERY	0	75	0	0	1	0	0	**76**
GROS-ISLET	1	40	5	1	0	1	0	**48**
LABORIE	3	48	2	1	0	1	0	**55**
MARIGOT	0	12	0	0	0	1	0	**13**
MARISULE	2	2	1	2	0	0	0	**7**
MICOUD	0	27	0	0	0	0	0	**27**
PRASLIN	1	18	0	0	0	0	0	**19**
ROSEAU	1	0	1	1	0	0	0	**3**
SAVANNES BAY	1	25	0	0	1	0	0	**27**
SOUFRIERE	21	42	6	13	2	0	0	**84**
VIEUX-FORT	4	192	2	1	5	3	0	**207**
TOTAL	**72**	**642**	**56**	**28**	**11**	**12**	**1**	**822**

(Source: Department of Fisheries, Registration as of December 31, 2016)

Table 2-2 The number of registered fishers by site in 2016

SITE	FULL TIME	PART TIME	NONFISHER	TOTAL
ANSE LA RAYE	87	57	12	**156**
ANSE GER	2	0	0	**2**
BANANNES	62	54	17	**133**
CANARIES	77	45	17	**139**
CASTRIES	181	143	30	**354**
CHOISEUL	120	45	16	**181**
CUL DE SAC	0	3	1	**4**
DENNERY	201	108	53	**362**
GROS-ISLET	145	85	25	**255**
LABORIE	104	66	14	**184**
MARIGOT	10	3	3	**16**
MARISULE	4	10	2	**16**
MICOUD	129	104	9	**242**
MONCHY	6	8	0	**14**
PRASLIN	38	23	6	**67**
RIVER DOREE	15	10	0	**25**
ROSEAU	1	3	1	**5**
SAVANNES BAY	41	14	7	**62**
SOUFRIERE	129	87	11	**227**
VIEUX-FORT	354	201	66	**621**
TOTAL	**1706**	**1069**	**290**	**3065**

(Source: Department of Fisheries, Total Registered Fishers as of December 31, 2016)

2.2 Direction of fisheries development plan in St. Lucia

The Government of St. Lucia has formulated the "National Fisheries Plan 2013" with the target year of 2022, and has set forth the long-term objectives shown below.

【Long-term objectives】

By maximizing the potential long-term economic value of available fishery resources, fisherman will fulfill national wage standards and promote sustainable fishery and efficient fishery technologies. Through the above, they will promote medium to long-term economic prosperity in the fisheries sector. And to achieve this long-term goal, they have set the following seven strategies.

【Seven strategies from 2013 to 2022】

1) Institutional Strengthening
2) Strengthening stakeholder input into the decision making process
3) Improving the average income of fishers
4) Maintaining sustainable fisheries
5) Developing sustainable aquaculture
6) Enhancing onshore Ancillary Services
7) Strengthening the marine product distribution system

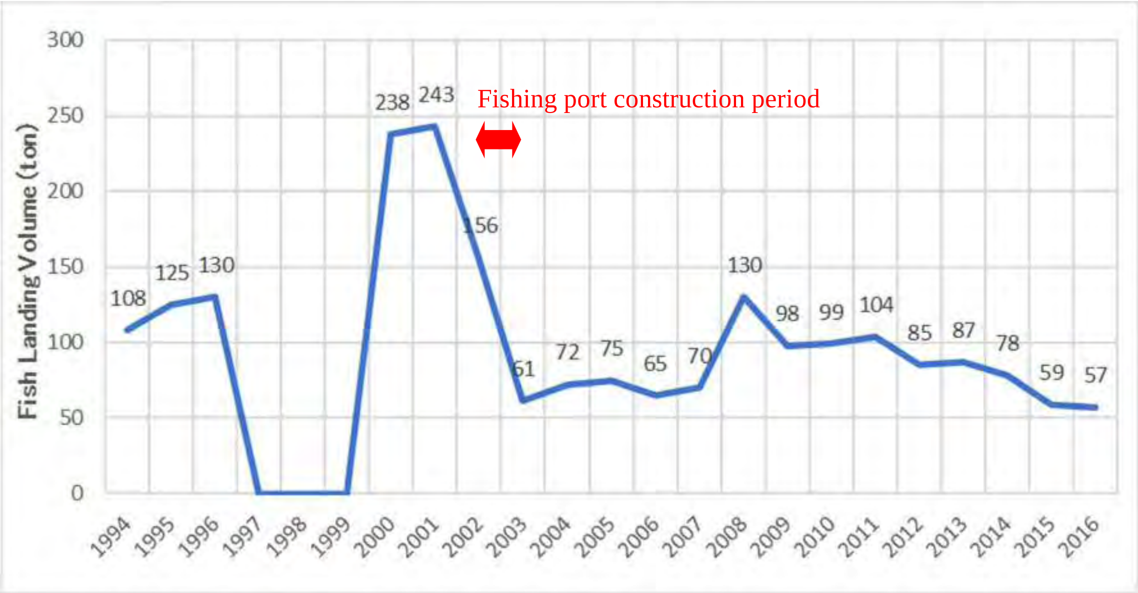
2.3 General conditions and issues of Choiseul fishing port

(1) Present conditions and issues of Choiseul fishing port

Figure 2-5 shows the transition of volume of fish landings in Choiseul fishing port from 1994 to 2016. It reached 238 ton and 243 ton in the year of 2000 and 2001 respectively. Later, because of deposition caused after the construction of the port, it decreased down to between 60 tons and 100 tons. Figure 2-6 indicates the volume of landings in 2016 by fish species in Choiseul fishing port. 26.4 ton of tunas (46.5%) occupies the largest portion, followed by 8.6 ton of dolphinfish (15.2%).

In Choiseul fishing port in 2016, total volume of landings was 56.7 ton (3.3% of the whole volume in Saint Lucia), the number of registered fishing vessels was 54, and the number of registered fishers was 165. According to the data provided by Department of Fisheries, the number of registered fishing vessels was 6th, the number of registered fishers was 7th, and volume of fish landings was 9th each from the top.

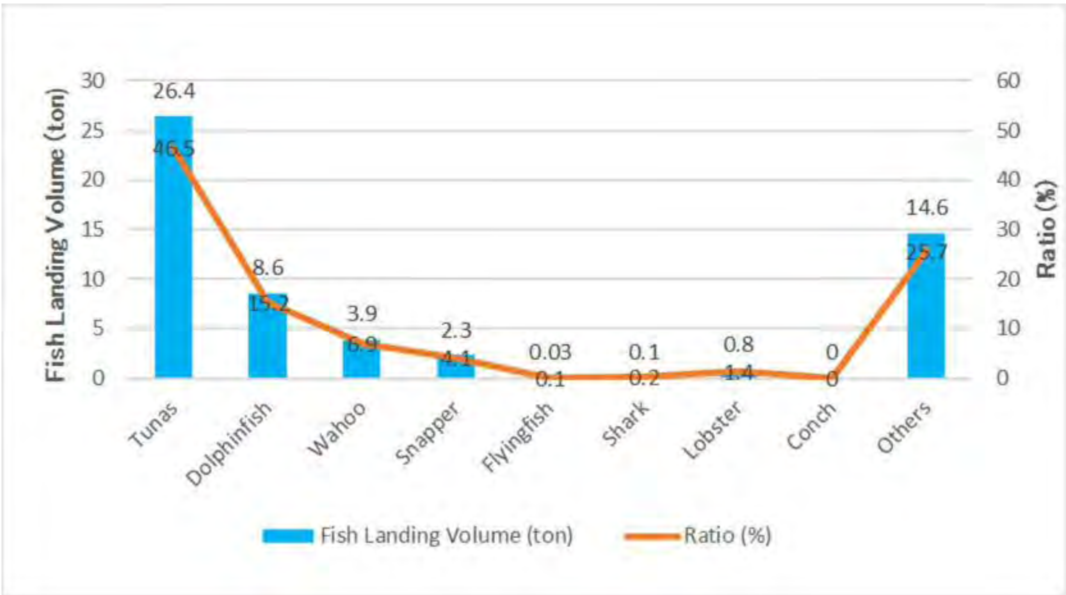
The problem in the Choiseul fishing port is a huge inefficiency for mooring fishing vessels and landing fish, caused by the deposition at the port entrance being an obstacle for the vessels to come in smoothly.



Note: Data for 1997 to 1999 are not available.

(Source: Statistics issued by Department of Fisheries, 1994-2016)

Figure 2-5 Transition of volume of fish landings in Choiseul fishing port from 1994 to 2016

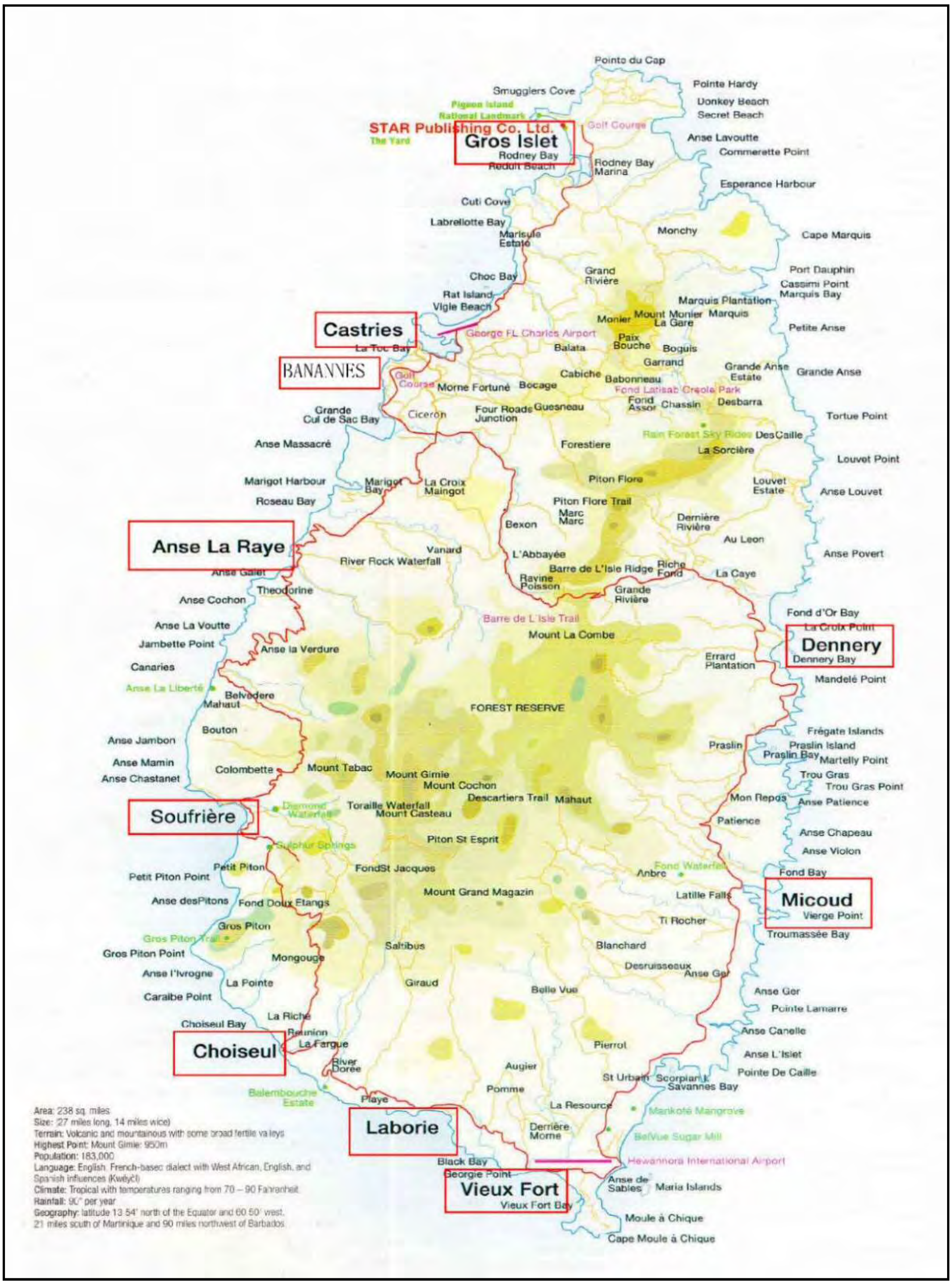


(Source: Statistics issued by Department of Fisheries, 2017)

Figure 2-6 Volume of landings by fish species in Choiseul fishing port in 2016

2.4 Survey results of fisheries facilities in Saint Lucia

From November 27 to 28, 2017, the study team surveyed the fisheries facilities in 10 sites in Saint Lucia (Castries, Banannes, Anse La Raye, Soufriere, Choiseul, Laborie, Vieux Fort, Micoud, Dennery, Gros Islet). As for 5 sites out of the 10 fish landing sites, the operation situations of updated and rehabilitated refrigeration facilities by the Project for Improvement of Fishery Equipment and Machinery in Saint Lucia in 2016 were confirmed.



(Source: Based on hearing to Department of Fisheries)

Figure 2-7 Locations of fisheries facilities in Saint Lucia

A Castries

(1) Name of facility: Castries Fishery Complex

(2) Project title: Fisheries Development Project in Saint Lucia (completed in 1989)
Fisheries Development Project (phase 3) in Saint Lucia (completed in 1996)
Fisheries Development Centre Construction Project (completed in 1997)

(3) Volume of fish landings, the number of registered fishing vessels and fishers (2016)
Volume of landings: 92.28 tons (5.3% of the whole)
No. of vessels: 85
No. of fishers: 324

(4) Outline of the fisheries facilities

1) Civil engineering facilities
・Fish landing jetty (29m)
・Boat Ramp (65m)

2) Functional facilities
・Process and sales facility
・Workshop
・Toilet and shower
・Administration and research facility
・Fishing gear locker (16)

3) Refrigeration equipment
・Freezing Storage (2.7 ton/day)
・Cold Storage (100 ton)

(5) Operational situations of facilities improved by the Project for Improvement of Fishery Equipment and Machinery (completed in 2016)

1) Condenser for refrigerating system

・Evaporative condenser for freezing storage	1 ls
・Evaporative condenser for cold storage	1 ls

2) Pickup trucks

・Single cabin	1 car
・Double cabin	2 cars

3) Subsidiary works

・Foundation for condenser	1 ls

【Operational situation】
・There are no problems.
・Equipment is well maintained by a resident refrigeration engineer of SFMC.

(6) Utilization
・It is a central core facility for fisheries distributions in Saint Lucia managed by SFMC.
・It is well used and maintained.

Photos of facilities (Castries)

Photo 2-1 Fishery complex

Photo 2-2 Fish landing jetty

Photo 2-3 Fish sales area

Photo 2-4 Fish processing area

Photo 2-5 Condenser for cold storage and freezing storage

Photo 2-6 Pickup truck

B Dennery

(1) Name of facility: Dennery Fishery Center
(2) Project title: Dennery Fish Landing-Base Construction in Saint Lucia (completed in 1994)
(3) Volume of fish landings, the number of registered fishing vessels and fishers (2016)
   Volume of landings: 359.84 tons (20.8% of the whole)
   No. of vessels: 76
   No. of fishers: 309
(4) Outline of the fisheries facilities
 1) Civil engineering facilities
   - Breakwater (110 m + 40 m)
   - Seawall (45 m + 45 m)
   - Fish landing wharf (70 m)
 2) Functional facilities
   - Administration office
   - Fish sales area
   - Workshop
   - Toilet and shower
   - Fishing gear lockers (40)
 3) Refrigeration equipment
   - Ice machine (2ton/day: plate ice)
   - Ice storage (10 ton)
   - Cold storage (10 ton)

(5) Equipment and operational situations renewed and improved by the Project for Improvement of Fishery Equipment and Machinery (completed in 2016)
 1) Ice plant
   - Ice machine (compressor) 1 ls
   - Ice machine (2ton/day: plate ice) 1 ls
   - Evaporative condenser for ice machine 1 ls
   - Ice storage（L 2,700mm × W 1,800 mm × H 2,200 mm） 1 ls
   - Control panel 1 ls
   - Ammonium detector and auto water sprinkler system 1 ls
 2) Solar power system
   - Photovoltaic panel and mount 1 ls
   - Connection box 1 ls
   - Power conditioner 1 ls
   - AC connection panel 1 ls
 3) Subsidiary works
   - New machine building 1 ls
   - Roof top water-proofing 1 ls

 【Operational situation】
   - There are no problems.
   - A pipe valve of condenser for ice machine on rooftop is damaged by salt. (Confirmed after advice from a refrigeration engineer of SFMC)

(6) Utilization
   - It is the only fishing port facing to the Atlantic Ocean in Saint Lucia, and accounts for 21% of fish landing volume, which is the second largest. Fishery center is managed by SFMC, and Fishermen's Co-operative is responsible for the management of fishing gear lockers and fuel facilities.
   - Facilities are well used and maintained.
   - Seaweed is carried into the basin of fishing port causing inconvenience for mooring fishing vessels.
   - Sedimentation of sand is found on a corner of the port, but it does not cause problems for wharf utilization. According to the manager of Fishermen's Co-operative, the sand is regularly removed.

Photos of facilities (Dennery)

Photo 2-7 Fishing port

Photo 2-8 Seaweed carried into the port

Photo 2-9 New machine building

Photo 2-10 Ice machine

Photo 2-11 Ice storage

Photo 2-12 Photovoltaic panel and mount

C Vieux Fort

(1) Name of facility: Vieux Fort Fishery Complex
(2) Project title: The Construction of Vieux Fort Fishery Complex in Saint Lucia in 2000
(3) Volume of fish landings, the number of registered fishing vessels and fishers (2016)
Volume of landings: 530.12 tons (30.6% of the whole)
No. of vessels: 207
No. of fishers: 555
(4) Outline of the fisheries facilities
1) Civil engineering facilities
・Breakwater (290 m + 90 m) ・Seawall (75 m + 45 m) ・Fish landing wharf (150 m)
・Slipway (60 m)
2) Functional facilities
・Cold storage building ・Administration office building ・Fish Market
・Fish handling shed ・Processed fish sales area ・Workshop ・Toilet and shower
・Fishing gear locker (108) ・Fishing gear sales area ・Canteen
3) Refrigeration equipment
・Ice machine (4 ton/day×2: plate ice) ・Ice storage (40 ton) ・Emergency generator
・Blast freezer (2 ton/day×2) ・Cold storage (360 ton)
(5) Operational situations of facilities improved by the Project for Improvement of Fishery Equipment and Machinery (completed in 2016)
1) Ice plant
・Compressor for ice machine 1 ls
・Ice machine (4 ton/day×2: plate ice) 1 ls
・Evaporative condenser for ice machine 1 ls
・Ice storage（L 7,200mm×W 3,600mm×H 2,400mm） 1 ls
・Control panel 2 panels
2) Cold storage and blast freezer
・Compressor for cold storage 1 ls
・Compressor for air blast 1 ls
・Cooling unit for cold storage at preparation room 1 ls
・Cooling unit for cold storage and air blast 1 ls
・Evaporative condenser for cold storage and blast freezer 1 ls
・Control panel for cold storage and blast freezer 2 panels
・Ammonium detector and auto water sprinkler system 1 ls
3) 5 ton refrigerated van 2 cars
4) Subsidiary works
・Demolition and restoration of the wall in the facility for ice machine 1 ls
【Operational situation】
・There are no problems.
・It is well maintained by a resident refrigeration engineer of SFMC.
(6) Utilization
・It is the biggest fisheries distribution facility in Saint Lucia, and the volume of fish landing is also the largest accounting for approximately 31%.
・Since the breakwater is constructed, the port can work as an evacuation port in case of a hurricane hit.
・SFMC manages the distribution processing facilities, Vieux Fort Council manages fish market, and Fishermen’s Co-operative is responsible for fishing gear lockers, canteen and fuel facilities.
・It is well used and maintained.
・For HACCP, it is planned to transfer changing room on fisheries processing booth which is now located outside .

Photos (Vieux Fort)

Photo 2-13 Fishing port

Photo 2-14 Fish landing wharf

Photo 2-15 Slipway and fishing gear lockers

Photo 2-16 Cold storage building

Photo 2-17 Fish market

Photo 2-18 Ice machine and ice storage building

Photo 2-19 Blast freezer

Photo 2-20 Cooling unit for air blast

Photo 2-21 Cold storage and air blast machine room

Photo 2-22 Cooling unit for cold storage

Photo 2-23 Condenser for cold storage and air blast

Photo 2-24 5 ton refrigerated van

D Anse La Raye

(1) Name of facility: Anse La Raye Fishery Center

(2) Project title: Improvement of Fishery Infrastructure in Anse La Raye in Saint Lucia
(completed in 2010)

(3) Volume of fish landings, the number of registered fishing vessels and fishers (2016)

Volume of landings: 61.82 tons (3.6% of the whole)

No. of vessels: 24

No. of fishers: 144

(4) Outline of fisheries facilities

1) Civil engineering facilities

- Fish landing jetty (48 m)

2) Functional facilities

- Administration office
- Fish market
- Workshop
- Toilet and shower
- Fishing gear lockers (30)
- Fishing gear sales area

3) Refrigeration equipment

- Ice machine (1 ton/day: plate ice), ice storage (2 ton)

(5) Operational situations of facilities improved by the Project for Improvement of Fishery Equipment and Machinery (completed in 2016)

1) Freezing system

- Compressor for ice machine 1 ls

【Operational situation】

- Existing old condenser for ice machine was out of order in June, 2017, and the ice machine is not in operation now.
- According to refrigeration engineer of SFMC who is in charge of the maintenance, Fishermen's Co-operative cannot replace the broken condenser into a new one because of its expense.

(6) Utilization

- It is a small fishery center occupying 4% of fish landing volume in Saint Lucia, managed by Fishermen's Co-operative.
- It is well used and maintained except for the broken ice machine.
- Since the beach was eroded in front of the fisheries facility in 2012, riprap work was executed as follow-up project by JICA in 2013. On November 2017, beach erosion has been solved.
- An event called "Fish Friday" is held on every Friday, and many tourists are entertained.

Photos (Anse La Raye)

Photo 2-25 Fishing port and recovered beach

Photo 2-26 Administration office

Photo 2-27 Workshop

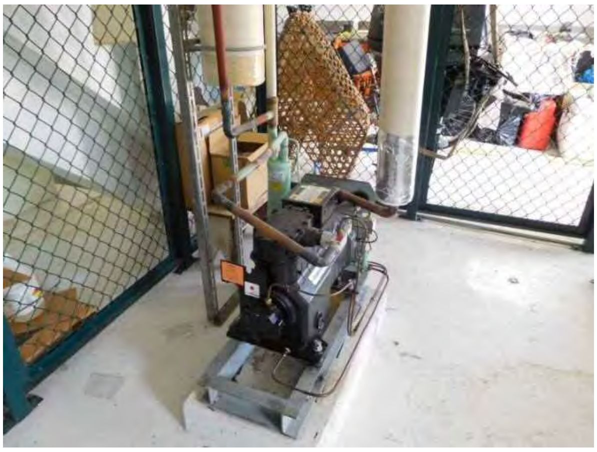


Photo 2-28 Compressor for ice machine

Photo 2-29 Broken condenser

Photo 2-30 Broken part of condenser

E Gros Islet

(1) Name of facility: Gros Islet Fishery Center

(2) Project title: Fisheries Development Project (phase 3) in Saint Lucia (completed in 1996)

(3) Volume of fish landings, the number of registered fishing vessels and fishers (2016)

Volume of landings: 93.91 tons (5.4% of the whole)

No. of vessels: 48

No. of fishers: 230

(4) Outline of fisheries facilities

① Civil engineering facilities

- Landing wharf (30 m)
- Slipway (45 m)

② Functional facilities

- Fish market
- Workshop
- Toilet and shower
- Fishing gear lockers (20)

(5) Operational situations of facilities improved by the Project for Improvement of Fishery Equipment and Machinery (completed in 2016)

1) Ice plant

・Ice machine (1 ton/day: flake ice)	1 ls
・Ice storage（L 2,700mm×W 1,800mm×H 1,600mm）	1 ls
・Evaporative condenser	1 ls
・Compressor for ice machine	1 ls
・Control panel	1 panel
・Ammonium detector and auto water sprinkler system	1 ls

【Operational situation】

- According to a refrigeration engineer of SFMC who is in charge of the maintenance, a needle valve of ammonium pipe is broken and automatic operation of ice machine is impossible on November 2017. The engineer is now considering measures taking contacts to the Consultant and Contractor.

(6) Utilization

- It is a small fishery center located at northern part of Saint Lucia and managed by Fishermen's Co-operative, accounting for approximately 5% of fish landing volume.
- It is well used and maintained except for the broken ice machine.

Photos (Gros Islet)

Photo 2-31 Fish landing wharf

Photo 2-32 Ice machine and ice storage

Photo 2-33 Ice machine

Photo 2-34 Compressor

Photo 2-35 Ice storage

Photo 2-36 Condenser

F Soufriere

(1) Name of facility: Soufriere Fishery Center

(2) Project title: The Project for Coastal Fisheries Development in Saint Lucia (completed in 2003)

(3) Volume of fish landings, the number of registered fishing vessels and fishers (2016)

Volume of landings: 36.66 tons (2.1% of the whole)

No. of vessels: 84

No. of fishers: 216

(4) Outline of fisheries facilities

1) Civil engineering facilities

- Fish landing jetty (23m)
- Slipway (4m)
- Seawall (110m+66m)

2) Functional facilities

- Administration office
- Ice machine and ice storage
- Fish market
- Workshop
- Toilet and shower
- Fishing gear lockers (40)

3) Refrigeration equipment

- Ice machine (0.75 ton/day: plate ice)
- Ice storage (1.5 ton)

(5) Operational situations of facilities improved by the Project for Improvement of Fishery Equipment and Machinery (completed in 2016)

(6) Utilization

- It is a small scale fishery center that accounts for about 2% of the total fish landing volume in Saint Lucia, and is operated by Fishermen's Co-operative.
- It is well used and maintained.
- Fishing gear sales area was constructed using a container by Fishermen's Co-operative in 2016.
- The wooden plate on superstructure of the fish landing jetty was damaged by a hurricane in 2016, and left as it is. Appropriate repair work is needed.

Photos (Soufriere)

Photo 2-37 Fish landing jetty

Photo 2-38 Administration office

Photo 2-39 Fish market

Photo 2-40 Fishing gear lockers

Photo 2-41 Workshop

Photo 2-42 Ice machine and ice storage

G Choiseul

(1) Name of facility: Choiseul Fishery Center

(2) Project title: Coastal Fisheries Development in Saint Lucia (completed in 2003)

(3) Volume of fish landings, the number of registered fishing vessels and fishers (2016)

Volume of landings: 56.70 tons (3.3% of the whole)

No of vessels: 54

No. of fishers: 165

(4) Outline of fisheries facilities

① Civil engineering facilities

- Breakwater (100m+27m)
- Fish landing wharf (100m)
- Slipway（30m×20m）
- Seawall (110m+66m)

② Functional facilities

- Administration office
- Ice machine and ice storage
- Fish market
- Workshop
- Toilet and shower
- Fishing gear lockers (40)

③ Refrigeration equipment

- Ice machine (1.1 ton/day: plate ice)
- Ice storage (2.2 ton)

(5) Operational situations of facilities improved by the Project for Improvement of Fishery Equipment and Machinery (completed in 2016)

(6) Utilization

- It is a small fishery center which accounts for about 6% of the total fish landing volume in Saint Lucia, and is run by Fishermen's Co-operative.
- It is well used and maintained.
- Inconvenient navigation at the port entrance occurs for fishing vessels due to sand sedimentation. Therefore, a local construction company executes small-scale dredging works once in 2 days.

Photos (Choiseul)

Photo 2-43 Fish market

Photo 2-44 Fishing gear sales area

Photo 2-45 Toilet and shower

Photo 2-46 Fuel facility

Photo 2-47 Ice machine

Photo 2-48 Ice storage

H Laborie

(1) Name of facility: Laborie Fishery Center

(2) Project title: Fisheries Development Project in Saint Lucia (completed in 1989)

(3) Volume of fish landings, the number of registered fishing vessels and fishers (2016)

Volume of landings: 71.78 tons (4.1% of the whole)

No. of vessels: 55

No. of fishers: 170

(4) Outline of fisheries facilities

1) Civil engineering facilities

- Space for vessels (2 places): non-existent

2) Functional facilities

- Fish market
- Workshop
- Toilet and shower
- Fishing gear locker (65): partially non-existent

3) Refrigeration equipment

- Ice machine (1.5 ton/day: plate ice)
- Ice storage (2.0 ton)
- Cold storage (40 ton)

(5) Operational situations of facilities improved by the Project for Improvement of Fishery Equipment and Machinery (completed in 2016)

- Not developed

(6) Utilization

- It is a small-scale fishery center that accounts for about 4% of the total fish landing volume in Saint Lucia and is run by Fishermen’s Co-operative.
- The facilities are severely deteriorated because approximately 30 years have passed since the construction in 1989.
- Ice machine and cold storage have been out of order and not been used for many years.
- Importance of fishery center has been decreasing after construction of Vieux Fort fishing port nearby.
- The beach has been eroded in recent years.

Photos (Laborie)

Photo 2-49 Fishermen's Co-operative office

Photo 2-50 Fish market

Photo 2-51 Fishing gear lockers (severely deteriorated)

Photo 2-52 Jetty for tourism (not used for fish landing)

Photo 2-53 Eroded beach (1)

Photo 2-54 Eroded beach (2)

I Micoud

(1) Name of facility: Micoud Fishery Center

(2) Project title: Fisheries Development Project in Saint Lucia (completed in 1989)

(3) Volume of fish landings, the number of registered fishing vessels and fishers (2016)

Volume of landings: 113.93 tons (6.6% of the whole)

No. of vessels: 27

No. of fishers: 233

(4) Outline of fisheries facilities

1) Civil engineering facilities

- Place for vessels storage: non-existent

2) Functional facilities

- Fish market: non-existent
- Toilet and shower: Old facilities do not exist
- Fishing gear lockers (20): Old facilities do not exist

(5) Operational situations of facilities improved by the Project for Improvement of Fishery Equipment and Machinery (completed in 2016)

(6) Utilization

- It is a small-scale fishery center that accounts for about 6% of the total fish landing volume in Saint Lucia facing to the Atlantic Ocean, and is run by Fishermen’s Co-operative.
- The facilities are severely deteriorated because approximately 30 years have passed since the construction on 1989. Some facilities do not exist.
- Fishing vessels go to Dennery fishing port or Vieux Fort fishing port because there are not fish landing facilities at Micoud.
- Offshore reef protects from waves from Atlantic Ocean, but pathway between such reef is narrow and dangerous.

Photos (Micoud)

Photo 2-55 Panoramic view of Micoud

Photo 2-56 Mooring of fishing vessels (1)

Photo 2-57 Mooring of fishing vessels (2)

Photo 2-58 Existing building

Photo 2-59 New fishing gear lockers
(Constructed by the Government of Saint Lucia)

Photo 2-60 Existing building

J Banannes

(1) Name of facility: Banannes Fishery Center

(2) Project title: Fisheries Development Project in Saint Lucia (completed in 1989)

(3) Volume of fish landings, the number of registered fishing vessels and fishers (2016)

Volume of landings: included in others

No. of the vessels: 49

No. of the fishers: 116

(4) Outline of fisheries facilities

1) Civil engineering facilities

・Place for vessels storage: non-existent

2) Functional facilities

・Fish market: Old facilities were not confirmed.

・Toilet and shower: Old facilities were not confirmed.

・Fishing gear lockers (25): Old facilities were not confirmed.

・Workshop: Old facilities were not confirmed.

(5) Operational situations of facilities improved by the Project for Improvement of Fishery Equipment and Machinery (completed in 2016)

・Not constructed.

(6) Utilization

・It is a small fishery center near Castries managed by Fishermen's Co-operative.

・Approximately 30 years have passed since the construction in 1989, and old facilities were not confirmed.

・Fishing vessels are directly pulled up on the beach since slipway is not constructed.

Photos (Bannane)

Photo 2-61 Mooring of fishing vessels

Photo 2-62 Fishing vessels on the beach (1)

Photo 2-63 Fishing vessels on the beach (2)

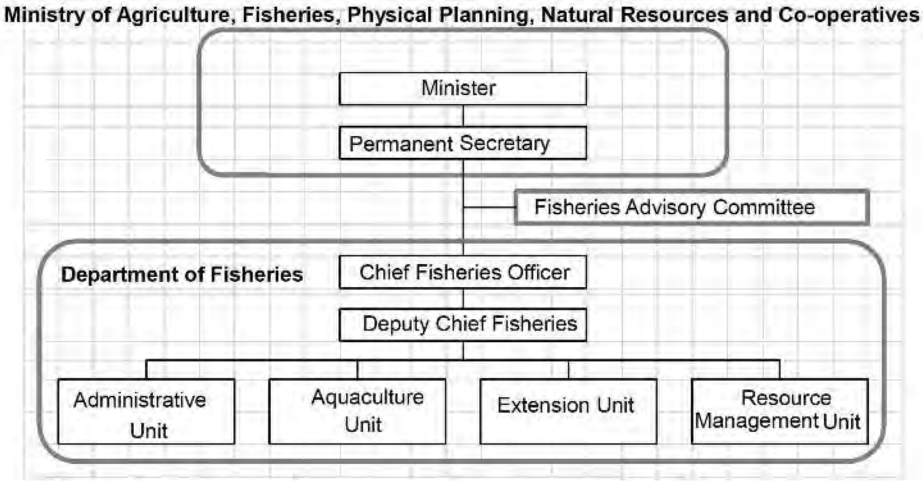
Photo 2-64 Fishing vessels on the beach (3)

Photo 2-65 Fishing gear lockers

Photo 2-66 Fish market

2.5 Roles and budget of related organizations for operation and maintenance of Choiseul fishing port

The responsible ministry for fisheries sector in Saint Lucia is the Ministry of Agriculture, Fisheries, Physical Planning, Natural Resources and Co-operatives, and the executing agency is the Department of Fisheries. The organization chart of the ministry is shown in Figure 2-8.



(Source: Ministry of Agriculture, Fisheries, Physical Planning, Natural Resources and Co-operatives)

Figure 2-8 Organization chart of the Ministry of Agriculture, Fisheries, Physical Planning, Natural Resources and Co-operatives

The Department of Fisheries is composed of 38 personnel as shown below.

- Chief Fisheries Officer (1)
- Deputy Chief Fisheries Officer (1)
- Senior Executive Officer (1)
- Administrative staff (3)
- Auxiliary staff (3)
- Aqua culturist (1)
- Aquaculture Officers (2)
- Pond Attendants (3)
- Fisheries Officer (1)
- Extension Officers (6)
- Fisheries Biologists (2)
- Fisheries Assistants (3)
- Data Clerks (1)
- Data Collectors (10)

Table 2-3 and 2-4 show the budget for 3 years of the Ministry of Agriculture, Fisheries, Physical Planning, Natural Resources and Co-operatives and Department of Fisheries.

Table 2-3 Budget for 3 years of the Ministry of Agriculture, Fisheries, Physical Planning, Natural Resources and Co-operatives

(Unit: EC$)

Expenditure	2016-2017 (Forward Estimate)	2015-2016 (Budget Estimate)	2014-2015 (Budget Estimate)
Total	20,215,556	35,177,156	38,639,260
Capital	3,473,456	18,435,056	22,000,600
Recurrent	16,742,100	16,742,100	16,638,600
-Fisheries Development	4,296,825	4,119,028	4,296,825

（1 US$=2.70EC$）

Table 2-4 Budget for 3 years of Department of Fisheries

(Unit: EC$)

Year	2016-2017 (Forward Estimate)	2015-2016 (Budget Estimate)	2014-2015 (Budget Estimate)
Total	1,694,785	1,813,371	1,782,886
Capital	1,435,800	1,650,100	1,943,129
Current	2,468,928	2,468,928	2,353,696

<Functions and situation of Fishermen's Co-operative>

There are 9 Fishermen's Co-operatives as stated below being in charge of operation and maintenance of fishing port facilities. Cooperative management by SFMC and Fishermen's Co-operative is made for 3 fishing ports: Vieux Fort, Dennery and Castries.

Gros Islet Fishermen's Co-operative (78)
Castries Fishermen's Co-operative (167)
Dennery Fishermen's Co-operative (113: East Coast)
Goodwill Fishermen's Co-operative (215: Vieux Fort)
Laborie Fishers and Consumers Co-operative (30)
Soufriere Fishermen's Co-operative (95)
Choiseul Fishermen's Co-operative (91)
Anse-la-Raye/ Canaries Fishermen's Co-operative (93)
East Coast Consumers and Fishermen's Co-operative (51)

(Source: Department of Co-operatives, September 2013)

Choiseul Fishermen's Co-operative was established on March 23rd, 1972, and consisted of 6 co-operative staffs and 99 members as of 2017.

Financial statement of Choiseul Fishermen's Co-operative in 2015 and 2016 is shown in Table 2-5. The year of 2015 marked a loss of EC$6,379, but the balance became EC$39,805 in black in 2016.

Table 2-5 Financial balance of Choiseul Fishermen's Co-operative in 2015and 2016

CHOISEUL FISHERMEN'S CO-OPERATIVE SOCIETY LIMITED

Statement of Income and Expenditure

For the year ended 31st December, 2016
With comparative figures for the year ended 31st December, 2015
(Expressed in Eastern Caribbean Dollars)

	Notes		2016	2015
Income	11	$	**1,263,674**	1,366,413
Less: Cost of sales	12		**1,117,923**	1,239,173
Gross profit			**145,751**	127,240
Add: Other Income	11		**93,297**	72,781
Less: Administrative, selling and general expenses	13-15		**199,243**	206,400
Net (surplus)/deficit for the year		$	**39,805**	-6379

(Source: Financial Statements 31st December 2016, Choiseul Fishermen's Co-operative)

2.6 Record of dredging works by the government of Saint Lucia after construction completion in 2003

Figure 2-9 shows an outline of the construction of Choiseul fishing port and the dredging works. Periods colored in pink mean the construction, and the periods colored in blue indicate the dredging works. The Choiseul fishing port has been constructed in 2002. The deposition was found prior to the completion of the construction, thus bathymetric survey started in December 2003 to confirm the deposition, and the first dredging work by backhoe was commenced in May 10, 2003. The dredging works were carried out intermittently up to March 20, 2006. The dredged amount was recorded since the dredging works were carried out as a part of the deposition countermeasure survey. It was comprehended that the dredging works had to be continued to maintain the necessary water depth in the fishing port, therefore as a drastic countermeasure, the additional breakwater of 40 m long has been constructed at the tip of the breakwater from April to July, 2008.

As mentioned in the Chapter-6, the construction of the additional breakwater has changed the sand inflow routes and increased the deposition. Referring to a photo as of November 14, 2015, the port entrance was completely closed and boats that could not enter the port were landed on the outside beach.

The second dredging works started on December 23, 2016, and have been almost continuously executed. The backhoe has been used in the second dredging works. The differences are that the port entrance is dredged, and the dredging works are carried out by local owner of the backhoe as a volunteer (according to the owner). However, the dredged sand seems to be sold as construction materials.

Photos imply that the government of Saint Lucia carried out dredging works in the port and the port entrance. However, the dredged amount and who have carried out the dredging works are unknown. In other words, the fact that the government of Saint Lucia executed the dredging works are not confirmed.

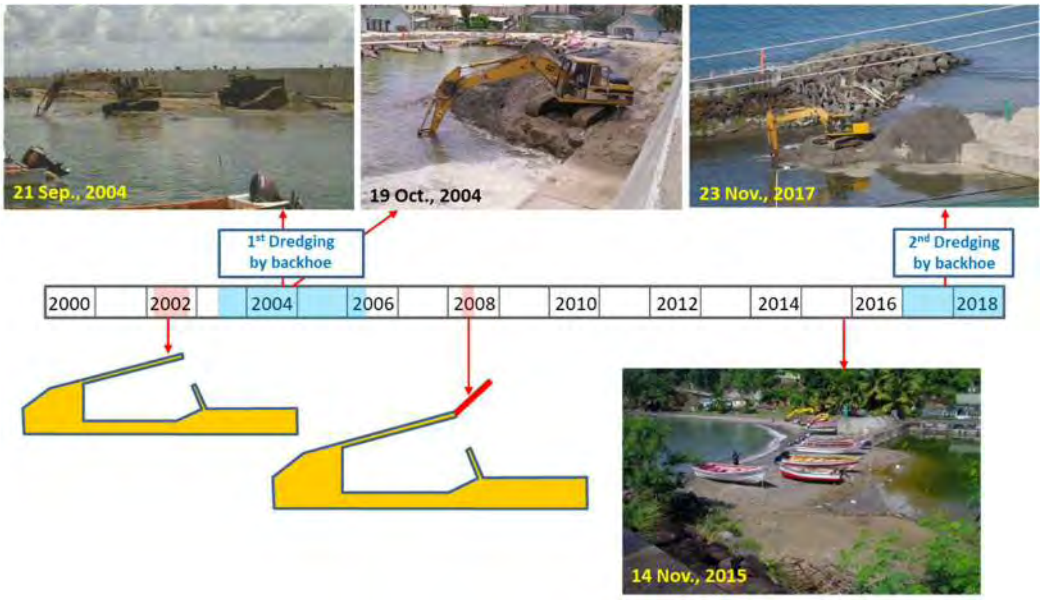


Figure 2-9 Construction of Choiseul fishing port and dredging works

The first and second dredging works are explained as follows.

【The first dredging works】

Records of the first dredging works are summarized in the report[1)] with results of bathymetric survey of 50 times conducted to monitor the deposition for the same period. Table 2-6 shows the dredging period and dredged amount. The total amount is 9,170m3. Yearly amount of the deposition can be estimated from this data.

【Reference】

[1)] ECOH CORPORATION : Proposal of the study for sedimentation mechanism and the maintenance method in Choiseul Fishing Port, page 23, August 2006

Table 2-6 Record of the dredging works in the port

Period	Dredged Amount (m^3)
May 10 to 24, 2003	700
May 3 to 17, 2004	800
July 2 to 9, 2004	2,500
September 20 to November 22, 2004	1,800
August 10 to 24, 2005	870
February 20 to March 20, 2006	2,500
Total	9,170

Figure 2-10 shows the deposited amount changes and dredged amount calculated by data obtained from monitoring 50 times. At the incipient stage, the deposited amount gradually increases, but the amount is kept at a certain amount after March 2004. Therefore, the dredged amount and the sand inflow amount can be regarded as being balanced. Then, as dredged amount for monitored 1,211 days is 9,170 m^3, yearly sand inflow amount to Choiseul fishing port can be calculated as follows.

$$9{,}170\ m^3 \times 365\ \text{days} / 1{,}211\ \text{days} \ = \ 2{,}764\ m^3 \qquad (1)$$

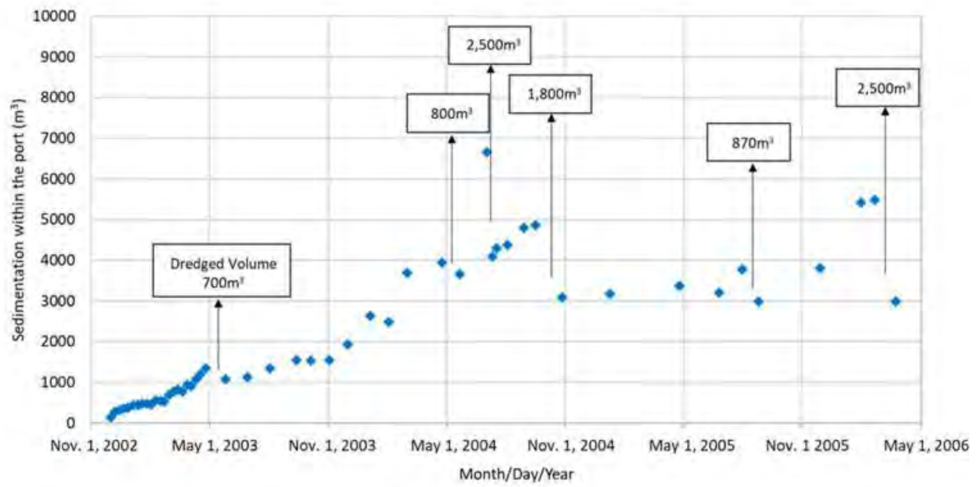


Figure 2-10 Deposition amount changes and dredged amount

【Second Dredging Works】

The dredging work by the backhoe during the first site works, which has been confirmed by the study team in November 2017, is reported here.

Photo 2-67 shows the dredging work with the backhoe. Dredging works could be seen 7 times out of 13 days when the study team visited there. However, if the surface of the sand piled on the ground was moist, it was judged that the dredging work was executed just before even without the backhoe in the photos. Most of the on-site stay was in the morning time, and the frequency of confirmed dredging work in the limited time was an about once in 2 days on average. The dredging work seems to be executed at fairly short intervals. The significant wave height observed in this period, which area is about 10 m depth, was approximately 0.4 m. Thus, even on a calm day, sand is steadily deposited at the port entrance.

Sand removed from the port entrance by dredging work was temporarily piled on the beach located on the north of the groin, and then it was often taken out by trucks as seen in Photo 2-68.

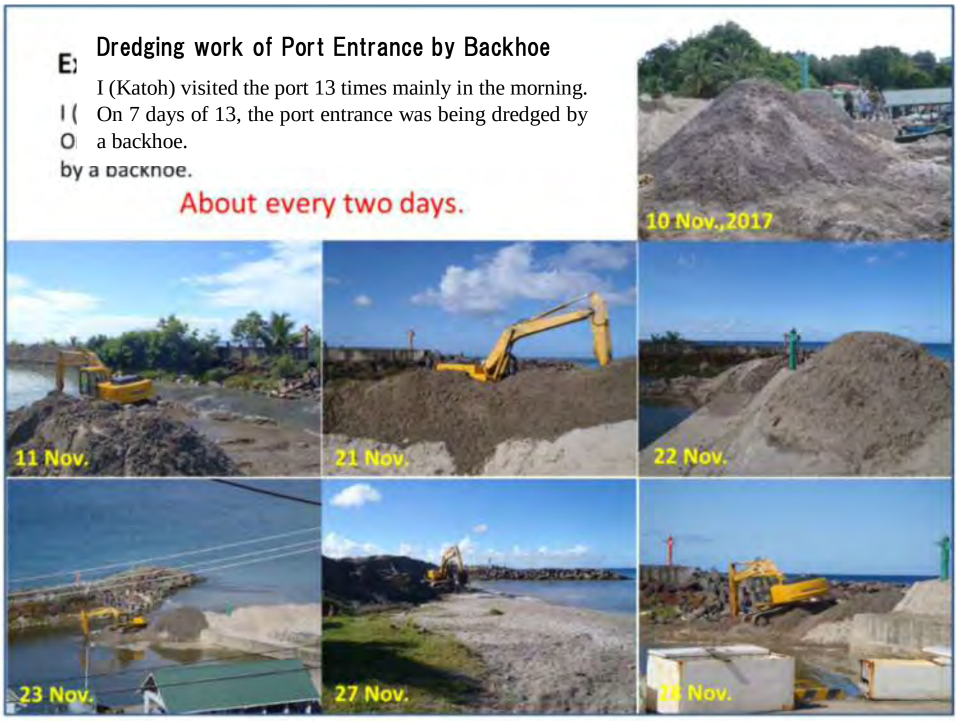


Photo 2-67 Dredging works in the port entrance by backhoe (November 2017)

Photo 2-68 Transportation of dredged sand by truck (November 2017)

Photo 2-69 is the conditions of the port entrance on Saturday, November 18, 2017 and Tuesday, November 21, 2017. Comparing 2 photos, the water on the left photo (day of 18) is clear, while the water on the right one (day of 21) is turbid. This is because dredging work by a backhoe was executed just before photo on the right was taken. The same reason can apply to the fact that the sand dredged and piled on the ground in front side of the right photo (day of 21) looks dark. In the photo on the right (day of 21), some ladders are left on the wave dissipating blocks. These ladders are used for pulling up fishing boats on a slipway or a sandy beach. The fact that such ladders are left there means that sand was deposited at the port entrance from 18 to 21 on Saturday to Tuesday and resultantly fishing boats could not sail themselves. In other words, although maintenance dredging work was executed at the port entrance with backhoe, it was not always enough and there were sometimes problems for fishing boats entering and leaving the fishing port.

Photo 2-69 Port entrance, November 2017: Left 18th (Saturday), Right 21st (Tuesday)

Photo 2-70 shows the conditions of the port entrance when the study team went out for regular inspection of the wave gauge on Tuesday, December 5, 2017. The study team could leave the port with the support of three young people who passed by. After regular inspections at offshore, the survey team could enter the port smoothly. It means dredging works at the port entrance by backhoe was completed. After all, sometimes it seems to be difficult for self-sailing.

Photo 2-70 Port entrance when self-sailing becomes difficult on December 5, 2017

Another weakness of dredging work by backhoe is that the dredging area is limited to only the reach of the backhoe. As shallow area is left outside of the reach, fishing boats have to be pushed when passing through such area as shown in Photo 2-71.

Photo 2-71 The remaining shallow area after dredging by backhoe on November 24, 2017

The above is the conditions of the dredging work by backhoe confirmed at the time of the first site works. After that, it seems that significant improvements have been made to the dredging method by backhoe, which is explained later.

On January 4, 2018 as shown in Photo 2-72, the amount of deposition on the north side of the groin increased, and the width of the port entrance became extremely narrow. The port entrance was probably still passable since there were no fishing boats pulled up on the beach which were seen when the port entrance was completely blocked.

On March 24, 2018 as shown in Photo 2-73, the port entrance was blocked. The closure of the port entrance is considered as a temporary event because the dredging work was seemingly interrupted since backhoe is not in the photo, it was on Saturday, and fishing boats are not pulled up on the beach outside the port. It should be noted that, compared to Photo 2-72, the amount of deposition on the north side of the groin decreased and the port entrance width became wider.

On August 13, 2018 as shown in Photo 2-74, the amount of deposition on the north beach of the groin decreased, and the port entrance width became wider. Sand is transported around the tip of the groin and is deposited in the port. However, level of the deposition is not high because the deposition in the port looks dark and moist compared to Photo 2-73. The amount of deposition on the north side of the groin further decreased and the port entrance width further expanded.

Looking at the Photo 2-7 to 2-74 sequentially, it is clear that the amount of deposition on the north side of the groin gradually decreased and the width of the port entrance was widened. This is considered to be the result of a significant improvement of efficiency for the dredging work by backhoe.

Photo 2-72 Choiseul fishing port (Google earth; January 4, 2018)

Photo 2-73 Choiseul fishing port (Google earth; March 24, 2018)

Photo 2-74 Choiseul fishing port (Drone photo; August 13, 2018)

The new method of dredging work is specifically explained below. As seen in Photo 2-75, the backhoe was used to excavate a sandy beach 30 m away to the north from the groin on August 14, 2018. At this time, the deposition occurred in the port as confirmed in Photo 2-76. In other words, the backhoe was operated for excavation on beach without dredging in the port.

Photo 2-75 Excavation on the sandy beach on 11:17, August 14, 2018

Photo 2-76 Deposition in the port on 11:19, August 14, 2018

Photo 2-77 Excavation trace on sandy beach on 12:27, August 16, 2018

Photo 2-77 was taken afternoon on August 16, after two days from Photo 2-75, showing excavation trace on sandy beach. The sand piled up just aside looks dark and moist, thus excavation seemed to be carried out in the morning.

Photo 2-78 Recovery of excavation trace

Photo 2-78 shows the recovery condition of excavation trace. It was almost completely backfilled leaving only a slight depression on August 19. The excavation trace could not be found on August 23.

Sand for recovery was transported from the neighboring beach by waves. Photo 2-78 contains the evidence to support it. Photo 2-79 is an enlarged view of the sandy area where the trace was left. The upper Photo 2-79 shows excavation on the beach, and the topography of foreshore where the seaweed is washed up is a regular beach topography. On the other hand, in the middle photo, scarp is formed between the excavation site and the person sitting on the beach (see a further enlarged photo 2-80). And on August 23, it is recognized that the formation of the scarp extended all over the sandy beach. The scarp is a micro topography on sandy beach which is usually formed by sand transportation from foreshore to offshore in case of high waves. However, since the sea condition from August 14 to 23 was calm with a significant wave height of about 0.3 m, observed value, it is reasonable to consider that the scarp is formed by sand transportation in the longshore direction, from foreshore to the excavation site.

Photo 2-79 Scarp formed by sand being carried to the excavation site

Photo 2-80 Enlarged view of the Scarp on August 19, 2018

Similarly, in the area between the excavation site and the groin of the Choiseul fishing port, sand should have moved in the direction from the groin to the excavation site, which is in the opposite direction of sand transport causing the deposition in the port. On August 21, 2018, when this temporary reverse excursion occurred, the sand deposited in the port was dredged by the backhoe as shown in Photo 2-81.

Photo 2-81 Dredging work by backhoe on August 21, 2018

Photo 2-82 shows the condition before and after dredging work by the backhoe in the port. Upper photo, before dredging work, was taken on the day when the sandy beach was excavated, and deposition extended from the tip of the groin into the port was formed. The deposition partially appeared above the sea level. In lower photo, after dredging work, the deposition is completely removed, and it is seemingly the same condition as the dredging work was executed at the time of the construction of the additional breakwater as shown in Photo 2-83.

Photo 2-82 Comparison of before and after dredging work by backhoe

Photo 2-83 Choiseul fishing port on September 29, 2008

To summarize the dredging work by the backhoe implemented in August 2018, firstly, the beach about 30 m apart to the north from the groin was excavated to create a depression topography. Then, sand is transported from both sides to fill in the depression, which causes temporary sand excursion in the direction from the port entrance toward the excavation site. This sand excursion occurs in the opposite direction from the one that causes the deposition in the port. The sand is dredged by the backhoe while the sand excursion occurs in the reverse direction. Since sand is removed by excavation at sandy beach prior to the dredging work in the port, repetition of the excavation results in gradual decrease of the amount of deposition on the north side of the groin and widening of the port entrance.

The improved dredging work was commenced before March 24, 2018 (Photo 2-73).It is because, in the Photo 2-84, there is a concave dark area in the place surrounded by the red dashed line and this is considered to be a trace of sandy beach excavation.

Photo 2-84 Trace of sandy beach excavation on March 24, 2018

Above mentioned contents were explained to the officers of the government of Saint Lucia and persons related to Choiseul fishing port by lectures on December 4, 2017, August 7, 2018, and April 4, 2019 in the department of fisheries, the government of Saint Lucia.

【Addition】

On April 4, 2019, the project manager of the study team visited Saint Lucia to explain the surveyed result in Phase-1, and could have an opportunity of site reconnaissance though it was a limited time. Photo 2-85 compares the north beach of the Choiseul fishing port. The upper photo and lower photo were taken in November 18, 2017, and April 5, 2019 respectively. The same camera was used to take both photos from the location of the blue beacon installed at the tip of the groin. The red dashed line shown in the lower photo shows the shoreline of the upper photo. The erosion of the whole shoreline can be confirmed referring to the red dashed lines.

Photo 2-85 Comparison of whole north beach of Choiseul fishing port

Photo 2-86 compares enlarged views of the part squared by a yellow dashed line in Photo 2-85. The beach existed in 2017, but it is completely eroded and rocks are found there. Referring to a person in the photo in 2017, size of the rock can be understood. Photo 2-87 is taken at the north end of the north beach. In 2017, these rocks were covered by sand. The erosion is a result of "beach excavation near the groin".

Photo 2-86 Comparison of north end of north beach of Choiseul fishing port

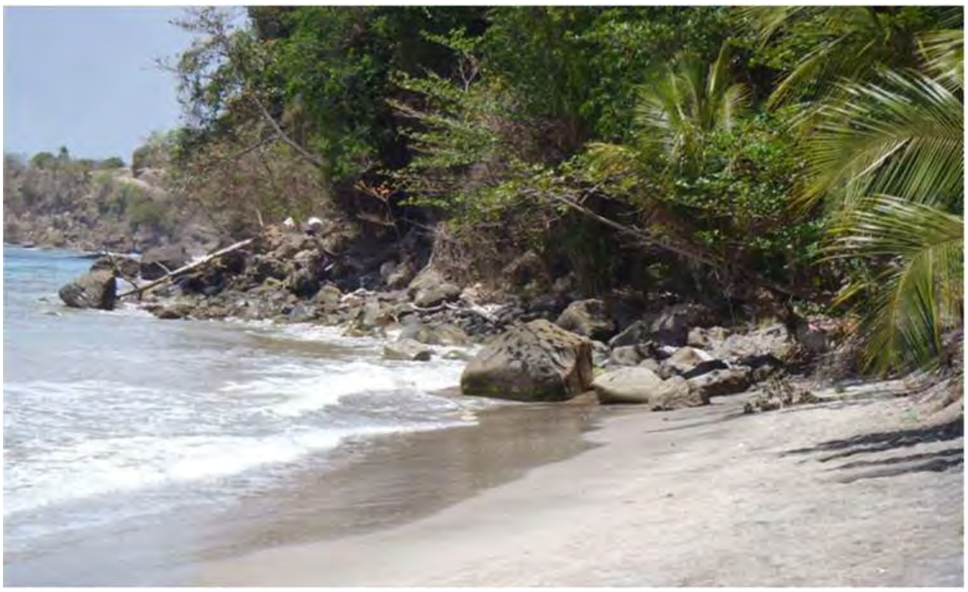


Photo 2-87 Exposed rocks by erosion in the north beach of Choiseul fishing port (April 5, 2019)

Photo 2-88 is a comparison of beach near the groin. Surely, the deposited sand was removed at the port entrance in 2017. Beach excavation started in 2018. Then, in 2019, the beach excavation was carried out in a larger scale. The owner of the backhoe seemed to notice that sand is collected by beach excavation. According to the owner, the excavated amount is approximately 200m^3/week, and at the most 50 trucks transport the sand out of the site.

According to Photo 2-88, 2 backhoes seem to be used for the excavation. However, the backhoe on the left in the bottom photo was completely broken as of 2015 and was abandoned as of 2019.

Photo 2-88 Comparison of beach near the sand groin

2.7 Extension construction of breakwater

A copy of the contract for the extension construction of breakwater was obtained from the Department of Fisheries of Saint Lucia. However, design drawings attached to the contract have been lost and not available.

2.8 Procedural survey of Environmental Impact Assessment (EIA) concerning dredging at the port entrance and dredging in the port

An Interview was conducted to the “Chief Physical Planning Officer” of the Ministry of Agriculture, Fisheries, Facilities Planning, Natural Resources and Co-operatives of the Government of Saint Lucia, to discuss the procedures for conducted environmental impact assessment on dredging at port entrance and in the port. Also, the Physical Planning and Development Act, Chapter 5.2 and the Guide to Obtaining Permission to Develop Land was collected.

According to the Chief Physical Planning Officer, the dredging work of the Choiseul fishing port is basically for maintaining and managing the existing facility and no EIA permission is necessary. However, it is concerned that treatment of dredged sand, generated by the maintenance dredging work has environmental impacts. Thus, submission of treatment plan to the Chief Physical Planning Officer in advance is recommended.

2.9 Permission to implement construction concerning dredging work at port entrance

According to the Chief Fisheries Officer of Department of Fisheries in Saint Lucia, the Department of Fisheries has applied for Construction Permission concerning the port dredging work to the Department of Infrastructure in advance, and has obtained approval.

2.10 Procedure of Environmental Impact Assessment (EIA) in case of implementing deposition countermeasure plan

According to the director of the facility planning authority, in the case of constructing structure as a deposition countermeasure (e.g., construction of a breakwater), the procedure of Environmental Impact Assessment (EIA), which usually takes about 6 months, is necessary.

2.11 Possibility of reuse of the Additional breakwater

To consider the countermeasure, it was confirmed in writing to the Chief Fisheries Officer of the Department of Fisheries, the Government of Saint Lucia, if the materials of the existing additional breakwater could be reused. According to the Chief Fisheries Officer, required procedure in the Government of Saint Lucia is as follows.

1) The consultant submits the detailed planning document to reuse the materials of the additional breakwater to the Permanent Secretary (in charge of Fisheries) of Ministry of Agriculture, Fisheries, Physical Planning, Natural Resources and Co-operatives.

2) After the Permanent Secretary of Ministry of Agriculture, Fisheries, Physical Planning, Natural Resources and Co-operatives confirms the content, the application is sent to the Ministry of Finance controlling all the governmental asset. It takes 2 to 3 weeks until the permission from the Ministry of Finance is issued.

3) After permission from the Ministry of Finance, the scope of the construction works is submitted to DCA to obtain the construction permission.

The letter issued by the Consultant and response letter are shown in the Annex.

Chapter 3　Transition and present status of port shape

Chapter 3 Transition and present status of port shape

Figure 3-1 shows transition of construction of Choiseul fishing port using drawings based on bathymetric surveys executed at the time prior to the construction, at the time of planning, construction completion of the port, and after construction of the additional breakwater.

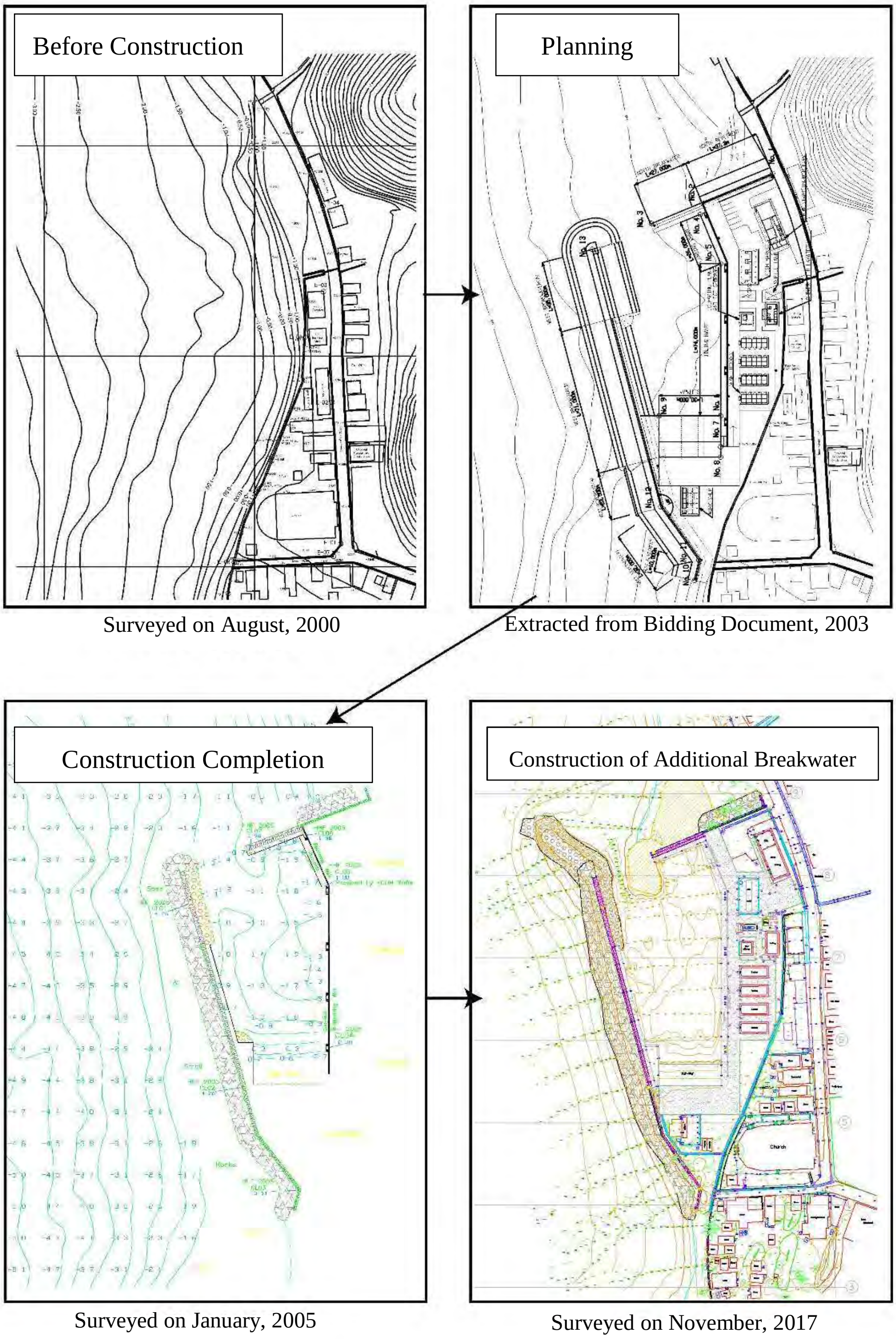


Figure 3-1 Transition of construction of Choiseul fishing port in 2000, 2003, 2005 and 2017

Chapter 4　Natural condition survey

Chapter 4　Natural condition survey

4.1 Wind conditions

Wind observations near Choiseul fishing port have been conducted continuously in the Hewanorra International Airport. And therefore, the record of wind observation and the data related with weather were collected visiting the metrological observatory in the Hewanorra International Airport on November 30.

Table 4-1 is the frequency table of the wind speed and the wind direction, and Figure 4-1 is the occurrence frequency figure.

The most frequent wind direction through a year is the wind direction of E with 49.5% occurrence ratio, and the wind direction of ENE with 22.6% occurrence ratio follows. The wind direction to make stronger wind more than 10 m/s that is closer to 10% occurrence ratio has also been occurred many times from the directions of E and ENE. The maximum wind speed is 23.13 m/s observed on June 28, 2017 during 15 years from 2003 to 2017.

Table 4-1 Occurrence frequency table of wind speed and wind direction

Wind direction: All direction
Season: All season
Duration: January 2003 to December 2017
Location: Hewanorra

16 direction
m/s

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	total
0- 2	4040 3.1	89 0.1	233 0.2	27 0.0	19 0.0	13 0.0	4 0.0	8 0.0	11 0.0	4 0.0	1 0.0	3 0.0	4 0.0	2 0.0	8 0.0	26 0.0	4492 3.4
2- 4	730 0.6	1316 1.0	2056 1.6	1754 1.3	827 0.6	568 0.4	374 0.3	258 0.2	215 0.2	111 0.1	98 0.1	71 0.1	56 0.0	27 0.0	29 0.0	169 0.1	8659 6.6
4- 6	82 0.1	796 0.6	2264 1.7	4582 3.5	7718 5.9	3296 2.5	1505 1.1	722 0.6	297 0.2	141 0.1	105 0.1	52 0.0	46 0.0	24 0.0	7 0.0	24 0.0	21661 16.5
6- 8	21 0.0	225 0.2	2683 2.0	10994 8.4	26365 20.1	5426 4.1	1233 0.9	409 0.3	186 0.1	60 0.0	22 0.0	24 0.0	41 0.0	8 0.0	1 0.0		47698 36.3
8- 10	3 0.0	63 0.0	1749 1.3	9148 7.0	22817 17.4	2737 2.1	198 0.2	71 0.1	49 0.0	15 0.0	2 0.0	5 0.0	16 0.0	8 0.0	1 0.0		36882 28.1
10- 12		17 0.0	514 0.4	2862 2.2	6787 5.2	607 0.5	42 0.0	21 0.0	17 0.0	5 0.0	1 0.0	2 0.0	8 0.0	2 0.0	1 0.0		10886 8.3
12- 14		5 0.0	78 0.1	277 0.2	466 0.4	59 0.0	9 0.0	1 0.0	1 0.0			2 0.0	2 0.0	2 0.0			902 0.7
14- 16			8 0.0	16 0.0	28 0.0	7 0.0	2 0.0	3 0.0	3 0.0				2 0.0	1 0.0			70 0.1
16- 18				1 0.0	4 0.0					1 0.0		1 0.0					7 0.0
18- 20			1 0.0		5 0.0								1 0.0				7 0.0
20- 22				1 0.0	1 0.0												2 0.0
22- 24					1 0.0												1 0.0
- 24																	
total	4876 3.7	2511 1.9	9586 7.3	29662 22.6	65038 49.5	12713 9.7	3367 2.6	1493 1.1	779 0.6	337 0.3	229 0.2	160 0.1	176 0.1	74 0.1	47 0.0	219 0.2	131267 100.0

Data obtained rate: 99.8 %　　missing data: 229　　Upper value: Occurrence number, Lower value: Occurrence frequency %

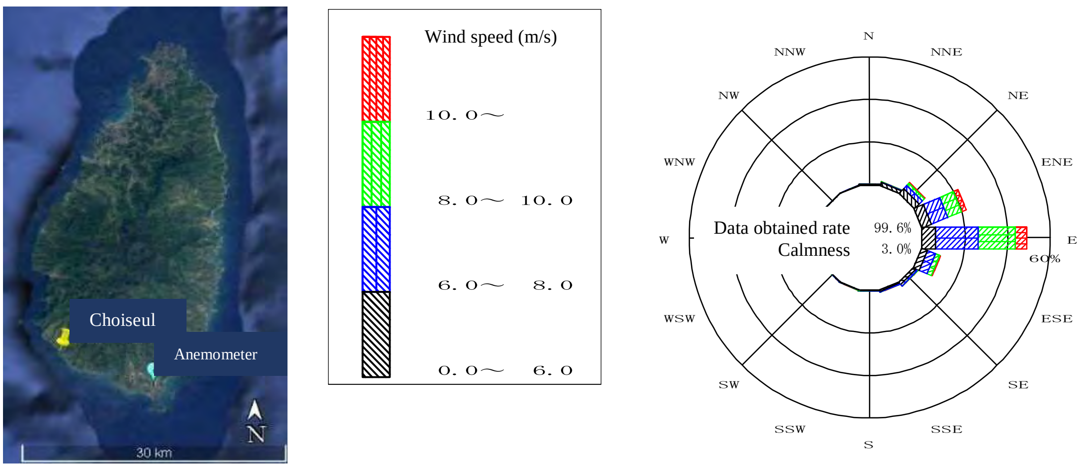


Figure 4-1　Occurrence frequency figure of wind speed and wind direction from 2003 to 2017

4.2 Hurricane

Figure 4-2 shows the hurricane generating points with ○, and the subsequent routes with red color solid lines during 11 years from 2007 to 2017. Especially, the hurricane shown by the blue line is Hurricane Tomas generated in October, 2010 and it brought the unexpectedly strong rain which would happen once in 180 years to Saint Lucia on October 30, 2010.

Hurricane generating places are situated around at lat. 15 degree to 30 degree and the generated hurricanes go to the north affected by the trade wind from the east. As Saint Lucia is nearly met with the southern limit of hurricane generating places, the hurricane generally moves to the direction away from Saint Lucia. Therefore, the possibility to directly hit Saint Lucia is low except like Tomas that was generated close by.

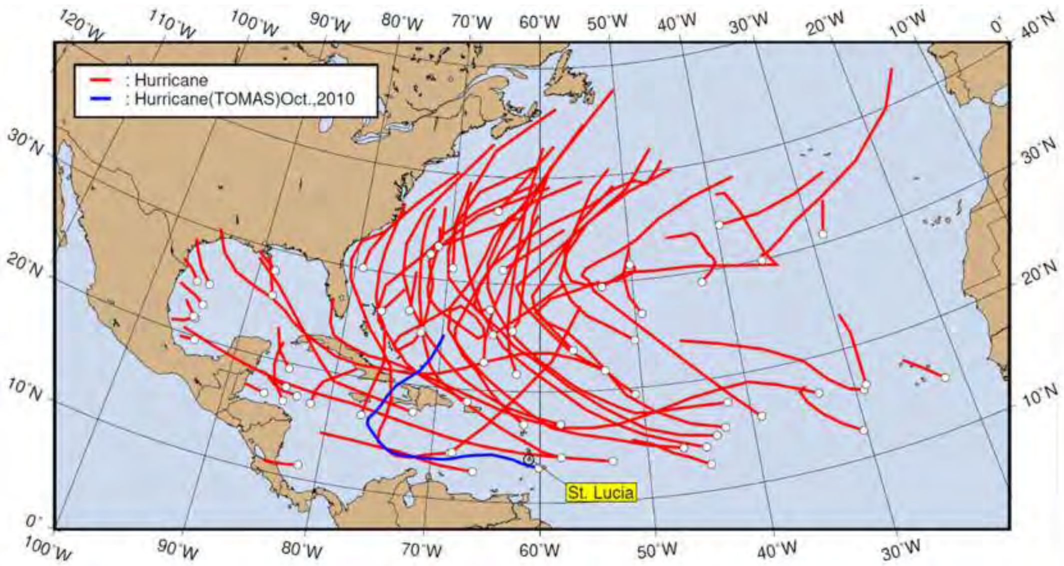


Figure 4-2 Hurricane generating points and the subsequent routes from 2007 to 2017

And most of the hurricanes generated around the southern limit are on the east sea being the opposite side of Choiseul fishing port. Choiseul fishing port is seldom affected by the high waves associated with the hurricanes in the east side. For example, Figure 4-3 shows the simulated wave distribution in case hurricane Lily was in the east sea. While the wave height in the east side of Saint Lucia is over 4 m, the west side where Choiseul fishing port is located is just about 1 m.

With the above, Choiseul fishing port is supposed not to be affected by hurricane.

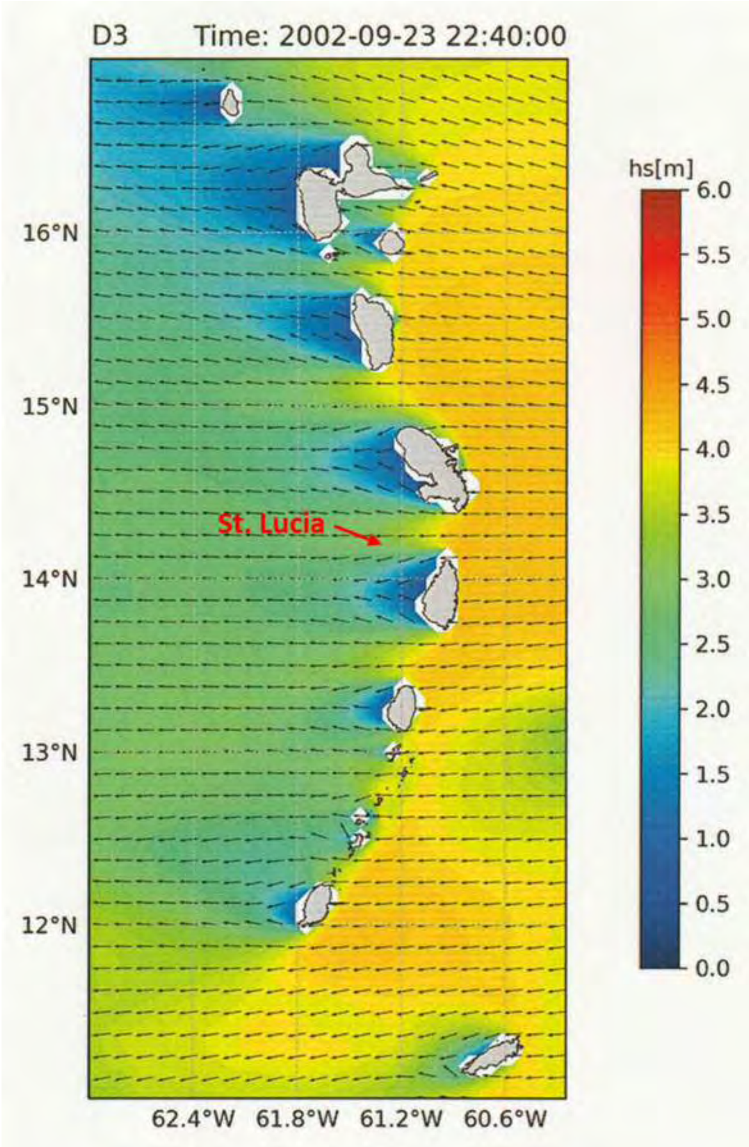


Figure 4-3 Wave distribution when hurricane Lili hit (hindcasting value)

4.3 Precipitation

Daily change of the precipitation collected from 2000 to 2018 are shown in Figure 4-4 to Figure 4-6. And the annual maximum precipitation value was abstracted from the figures and it was sorted out in Table 4-2.

According to these, the precipitation with 20 mm/day through a year is mainly generated. The rainy season is mostly from July to December and the annual maximum precipitation were observed 14 times in total that are 3 times/August, 3 times/September, 3 times/October, 3 times/November and 2 times/December.

The maximum precipitation in last 19 years was 593.1 mm observed in October, 2010 and 320.6 mm observed in September, 2016 follows.

Table 4-2 List of annual maximum precipitation

Year	Month & date	Precipitation (mm/day)
2000	February 21	133.4
2001	December 13	80.0
2002	April 9	98.4
2003	August 20	49.9
2004	November 23	72.1
2005	October 5	128.0
2006	August 24	70.6
2007	August 16	53.3
2008	October 11	66.8
2009	January 16	65.0
2010	October 30	593.1
2011	April 11	134.5
2012	November 12	78.4
2013	December 24	124.3
2014	November 8	68.3
2015	September 21	97.8
2016	September 28	320.6
2017	September 18	76.5
2018	No rain exceeding 30 mm	

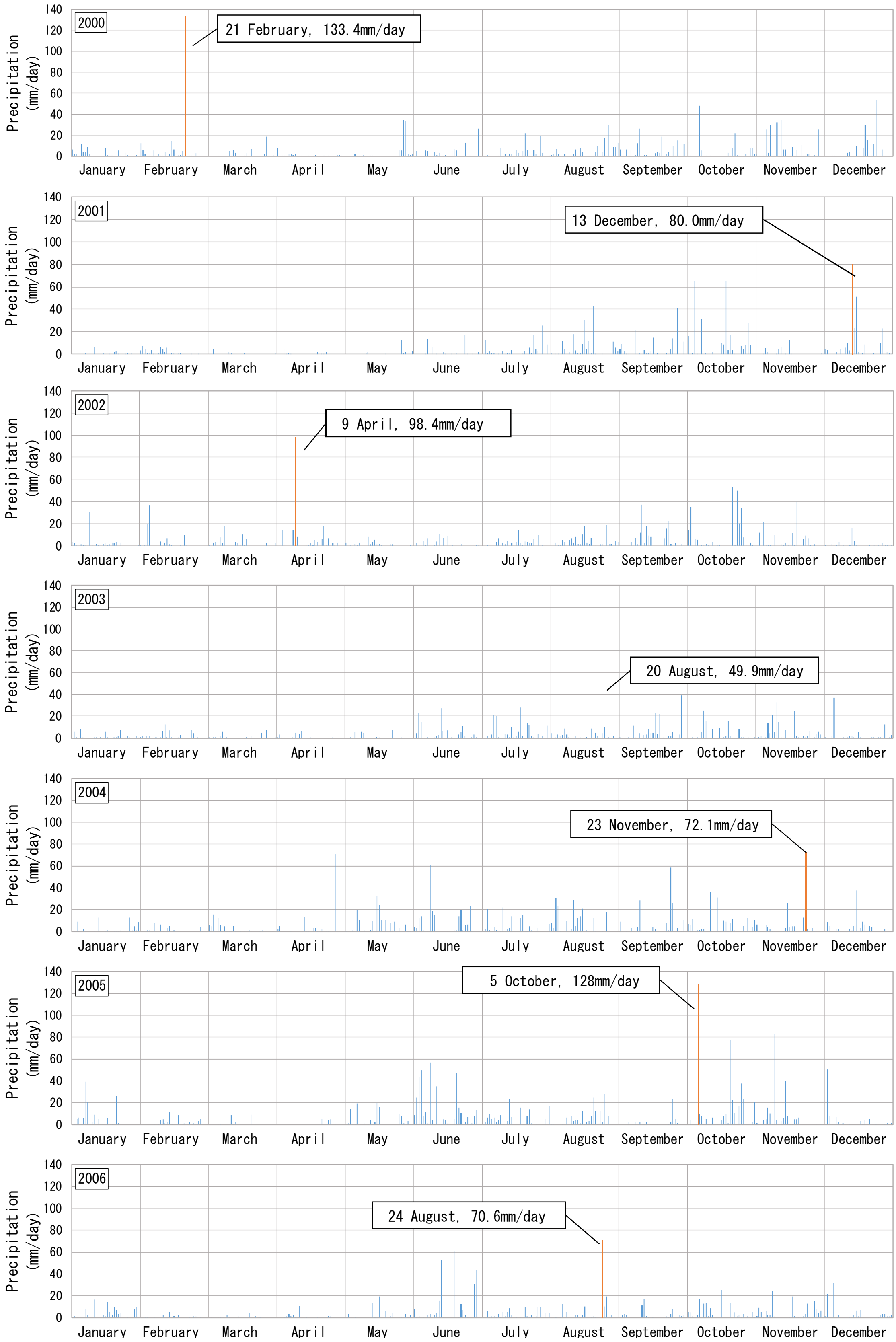


Figure 4-4 Daily change of precipitation from 2000 to 2006

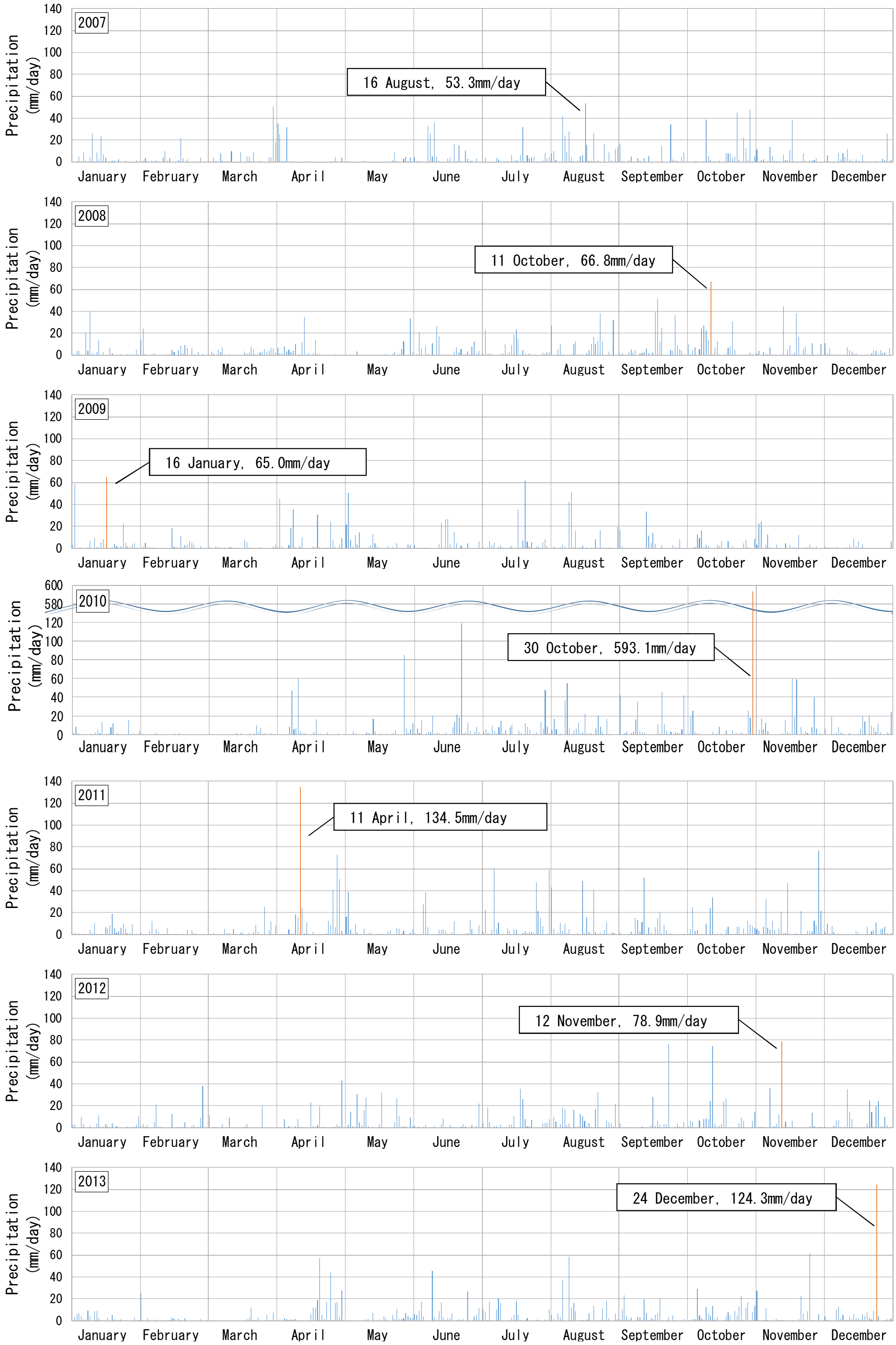


Figure 4-5 Daily change of precipitation from 2007 to 2013

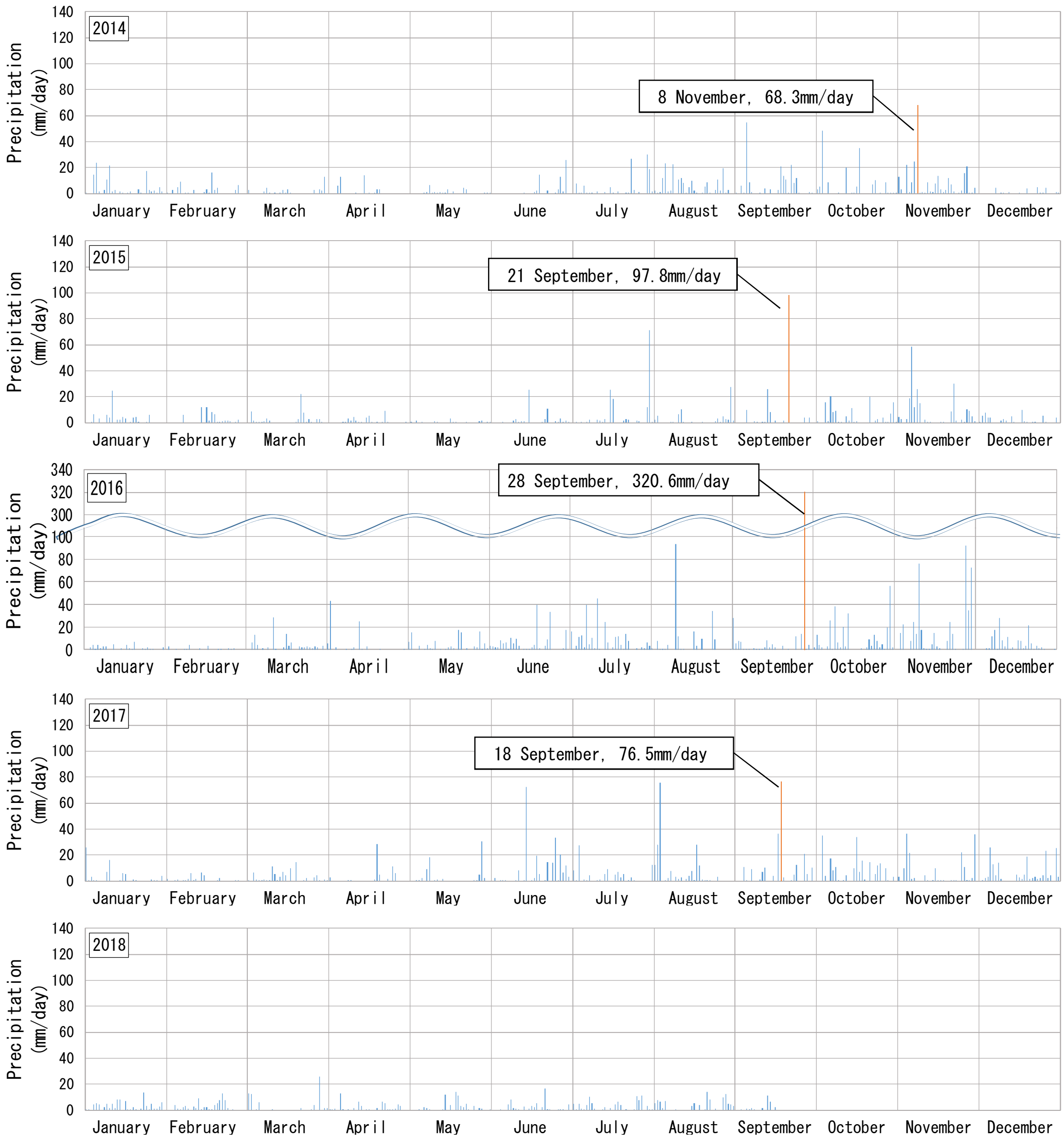


Figure 4-6 Daily change of precipitation from 2013 to 2018

4.4 Shoreline change around Choiseul Fishing Port

(1) Aerial photos

Aerial photos including Choiseul fishing port were collected from Saint Lucia Physical Planning.

Collected photos were rather old like 2009 as the newest and since even shooting intervals becomes more than 10 years, Google Earth pictures are also collected and utilized to understand the coastline conditions. Photo 4-1 and 4-2 show the collected aerial photos and Google Earth pictures (1941 to 2018).

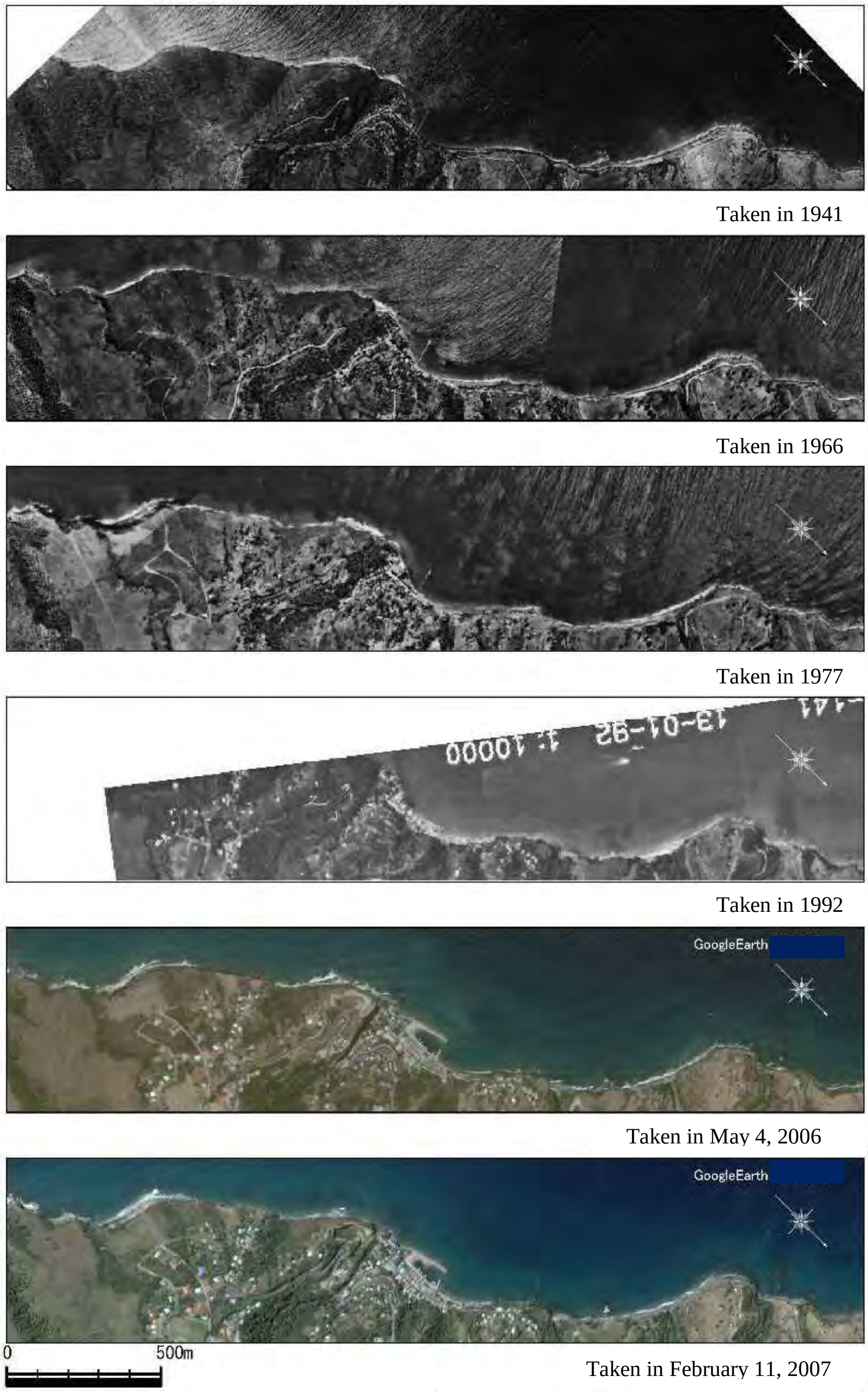


Photo 4-1　Aerial photos from 1941 to 2007

Taken in 2007

Taken in 2009

Taken in November 23, 2009

Taken in September 27, 2015

Taken in March 24, 2018

Photo 4-2　Aerial photos from 2007 to 2018

(2) Calculation of shoreline change volume

Based on the collected aerial photos for understanding shoreline change volume, the landforms of shoreline, coast structures, etc. were digitalized. That result is shown in Figure 4-7.

And then, using the digital data of each year, the shoreline change volume was calculated in the on-offshore direction. Figure 4-8 shows the coastal distribution of coastline change volume by shot, and Figure 4-9 shows the coastal distribution of shoreline change volume in comparison with the year of 1941 that is initial shot. With these, the following features can be observed around Choiseul fishing port.

① Cliff topography in the south side of Choiseul fishing port does not generate large change reaching the volume of 10 m change.

② Paying attention to the surrounding area of Choiseul fishing port, although the coastlines before the construction in 1941 to 1992 repeats the accretion and recession, but after the construction of Choiseul fishing port in 2002, in 4 terms that are from 1992 to 2006, 2007 to 2009, 2009 to 2015 and 2015 to 2018, the shoreline on the north side of Choiseul fishing port (near 2,100 m to 2,300 m) has greatly accreted and the volume of every accretion reaches 20 m to 30 m.

③ The shoreline around Choiseul fishing port has greatly accreted after 2002 when Choiseul fishing port was constructed and its accretion volume reaches 80 m.

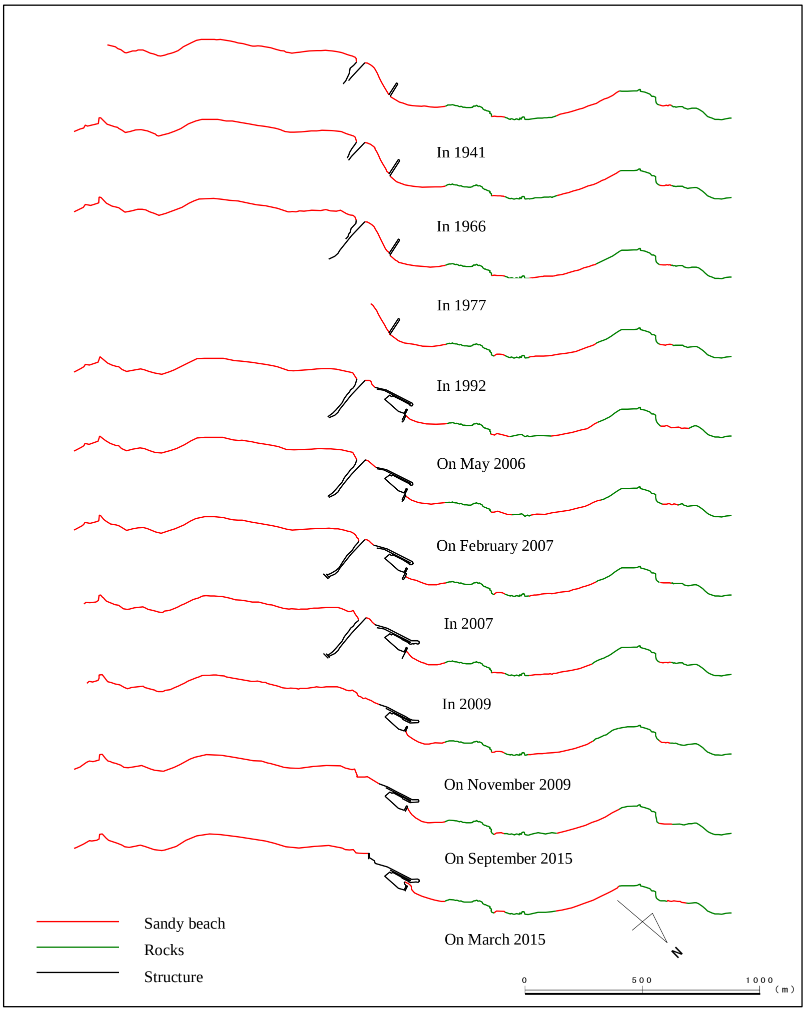


Figure 4-7 Plan view of topography of shoreline, coast structures, etc.

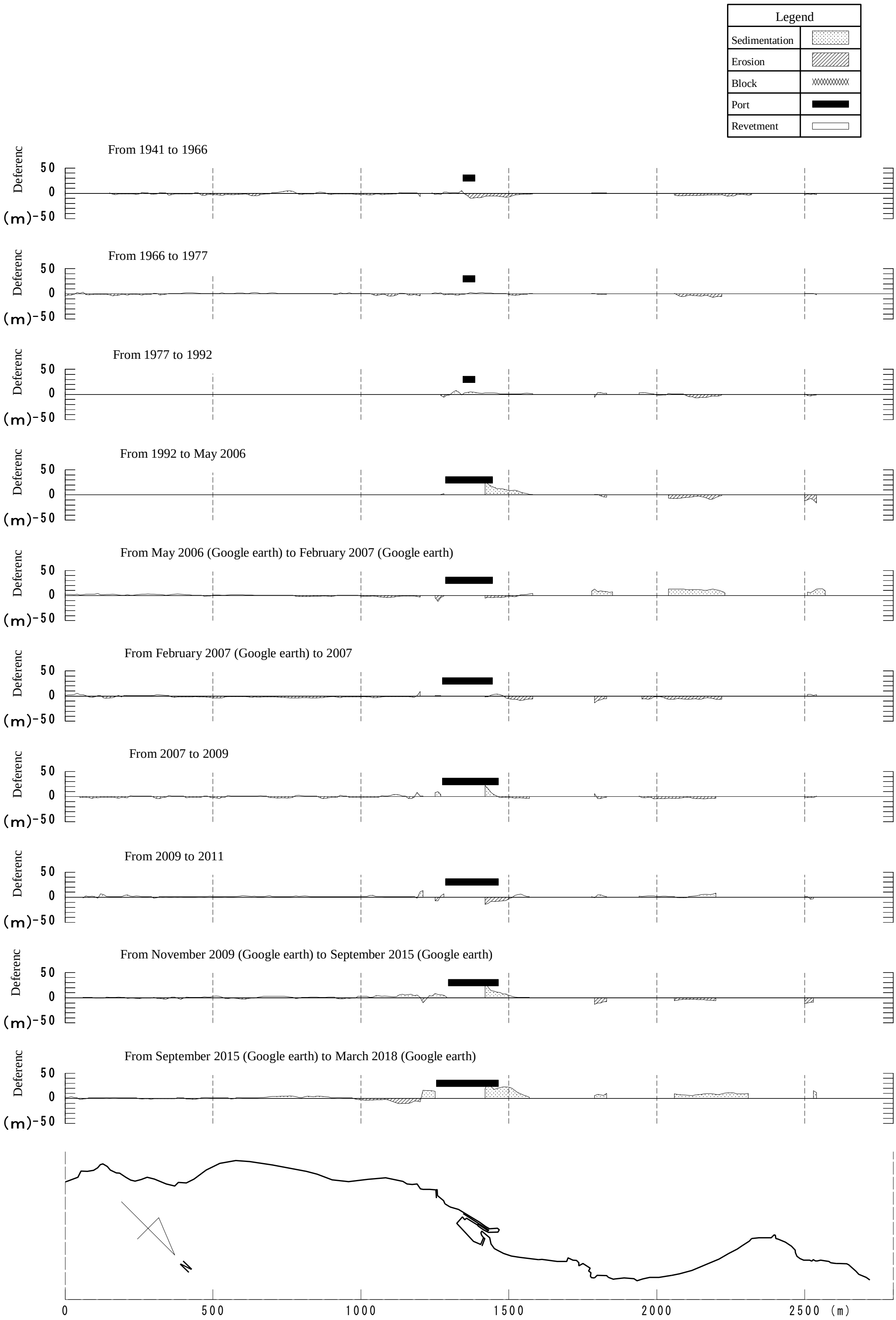


Figure 4-8 Coastal distribution of shoreline change volume by shot

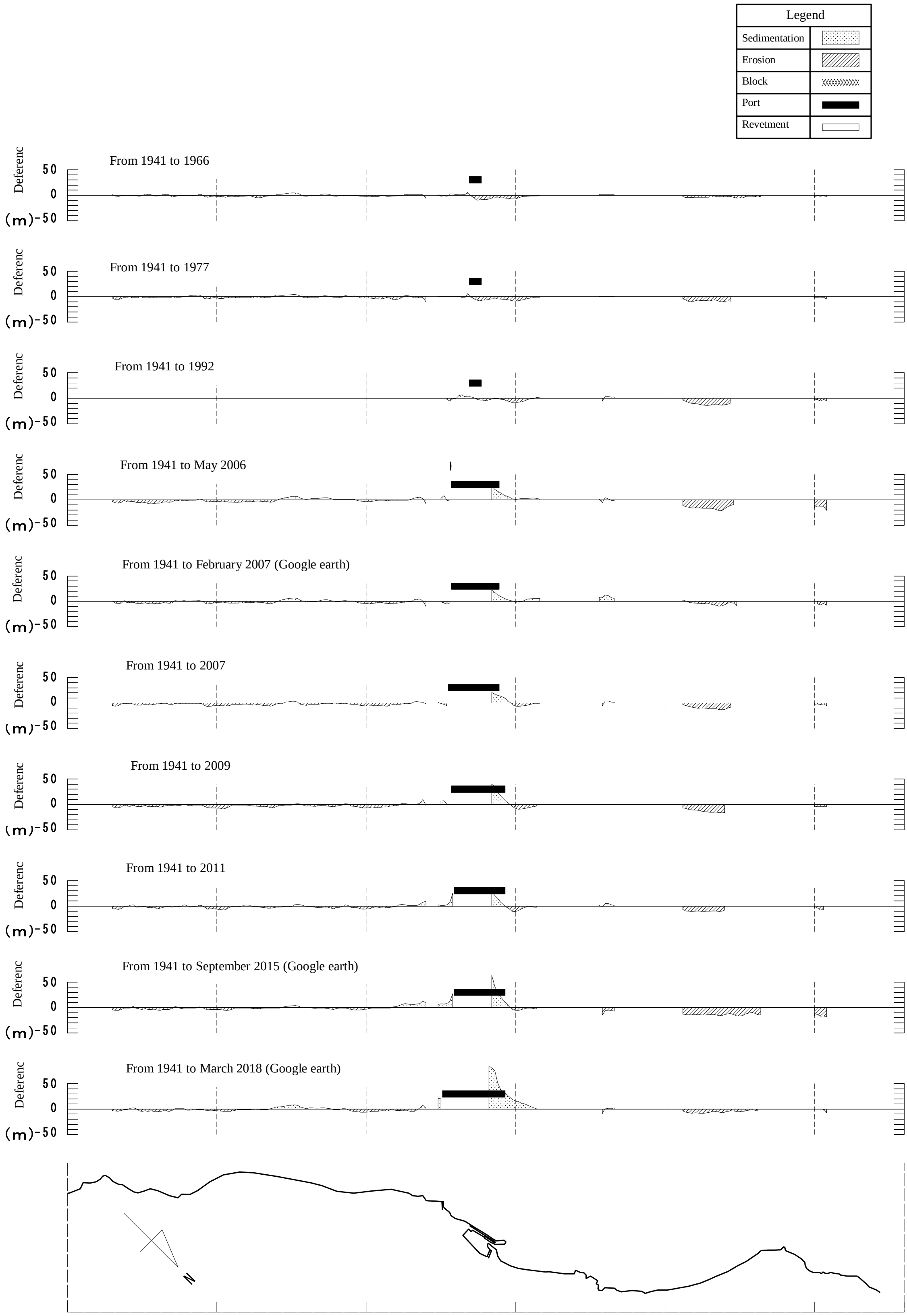


Figure 4-9 Coastal distribution of shoreline change volume (base year: 1941)

(3) Calculation of generated sand volume in association with recession of cliff topography

For the calculation of sand volume generated in association with the recession of cliff topography identified by digitalization of natural coast in aerial photo, the elevations of cliff topography were checked.

Figure 4-10 (upper and middle figures) shows the plan view of topography of which elevation in the Google Earth pictures are surveyed, and Figure 4-10 (lower figure) shows the coastal distribution of cliff topography elevation.

As the main feature, the elevation of south side of cliff topography next to Choiseul fishing port is exceeding 35 m as the maximum and the big scale sand supply to water area can be considered. The main cause of recession of cliff topography is considered to be the wave directly effecting on the cliff.

In the calculation of generated sand volume, the area where the wave attenuation reaching Choiseul fishing port is small and plus the elevation of cliff is high is targeted.

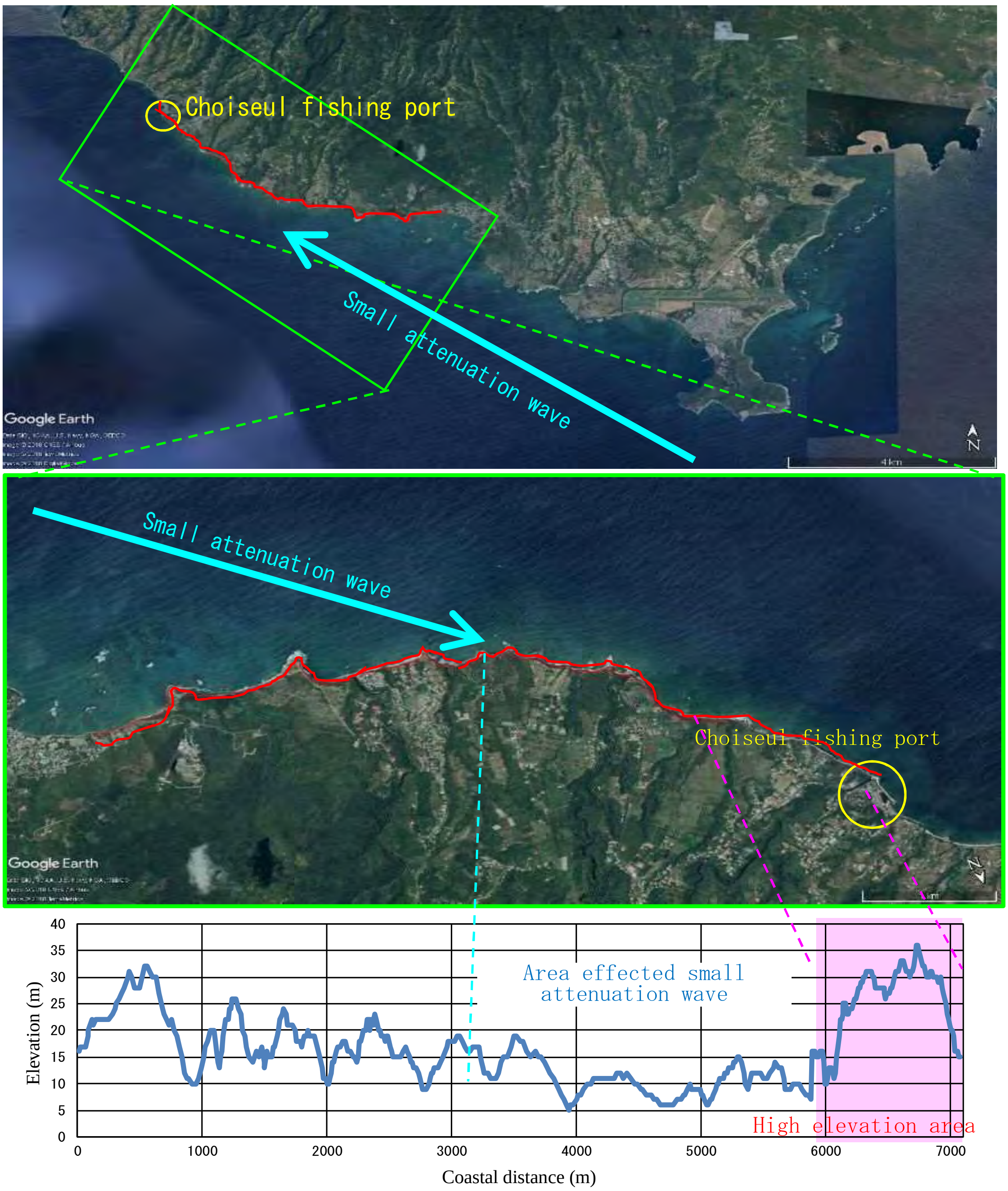


Figure 4-10 Reading places of cliff topography (upper and middle figures) and their elevations (lower figure)

4.5 Topographic Survey and Shoreline Survey

The topographic survey was made from November 16 to December 1, 2016 by the local survey company (Hart, Hutchinson & Field) consigned. The shoreline surveys were made 3 times in November 14, 22 and 30, 2017at the time of first site survey and also 3 times in August 10, 21and September 25, 2018 at the time of second site survey. Table 4-3 shows the coordinate and elevation of each benchmark and Figure 4-11 shows each location of the benchmark.

The results of topographic survey are shown in Figure 4-12 and the results of shoreline survey are shown as per Figure 4-13 and Figure-14.

Table 4-3 Coordinate and elevation of each benchmark

Benchmark	Latitude	Longitude	Elevation
GP01	Lati.13°46’ 29.80016”	Longi. 61°03’ 2.86970”	C.D.L +5.86m
CL01	Lati. 13°46’ 28.92031”	Longi. 61°03’ 3.69907”	C.D.L +4.26m
CL04	Lati. 13°46’ 26.68071”	Longi. 61°03’ 1.70921”	C.D.L +2.00m

Figure 4-11 Location of each benchmark

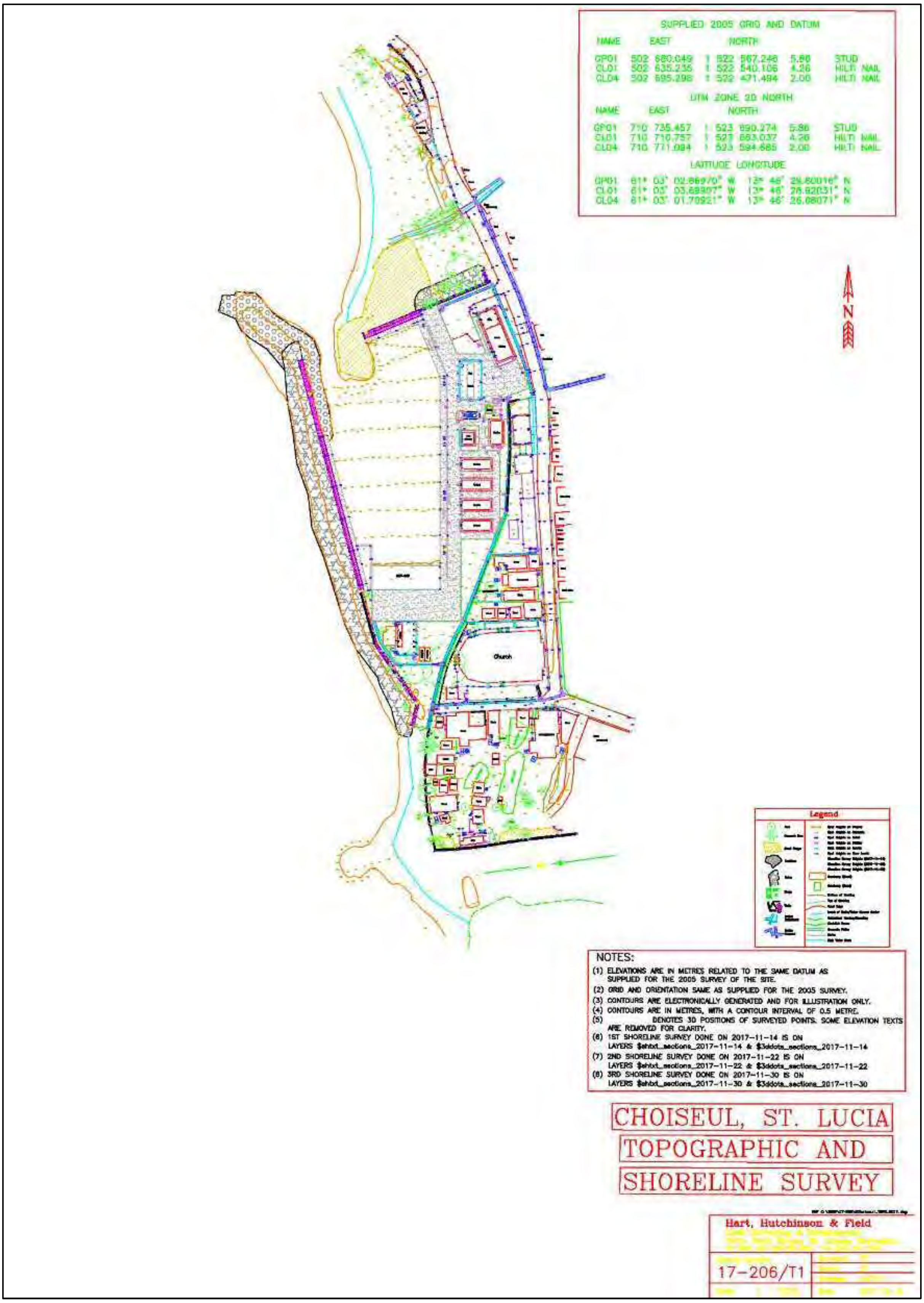


Figure 4-12　Topographic survey (November, 2017)

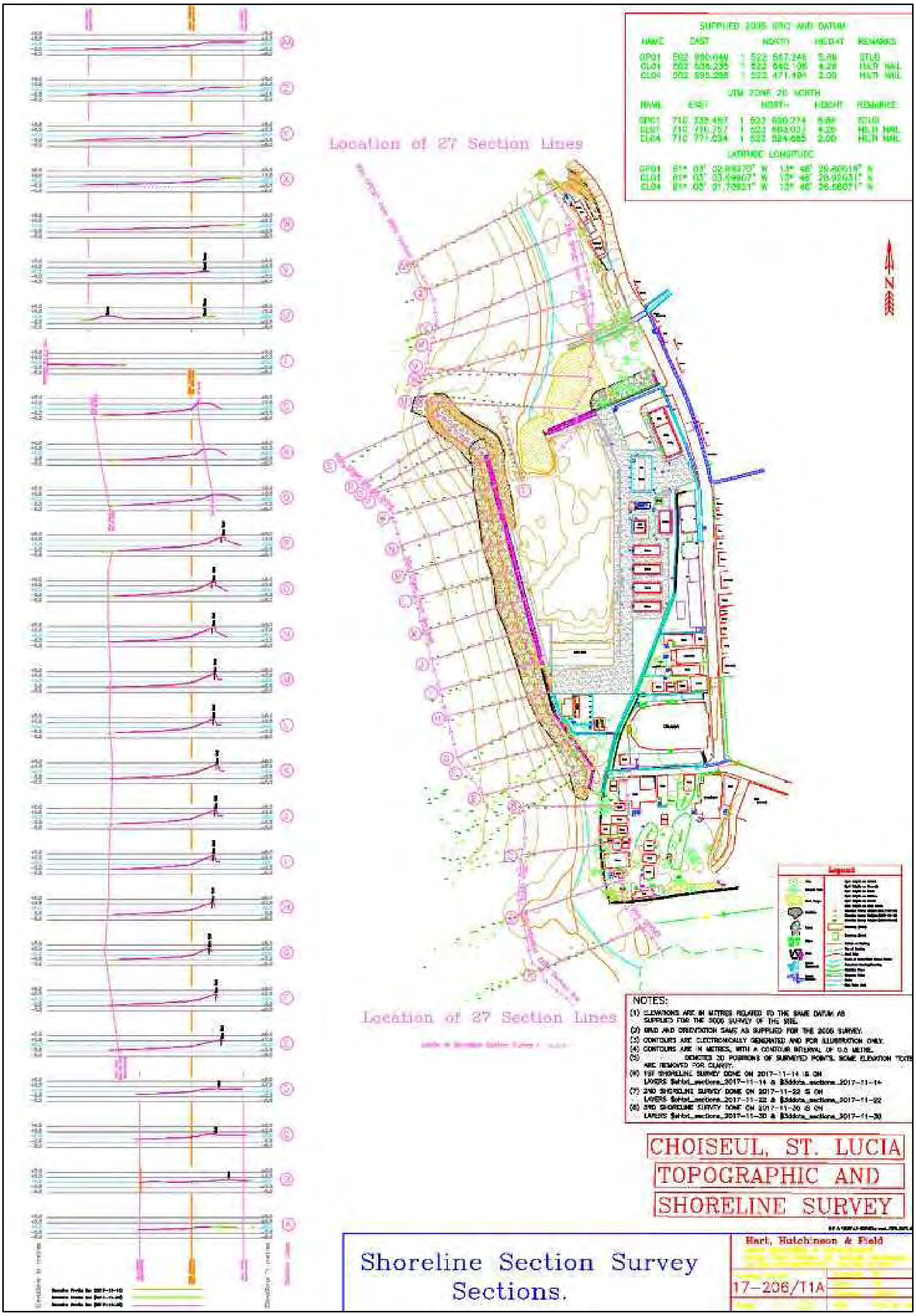


Figure 4-13 Shoreline survey (November, 2017)

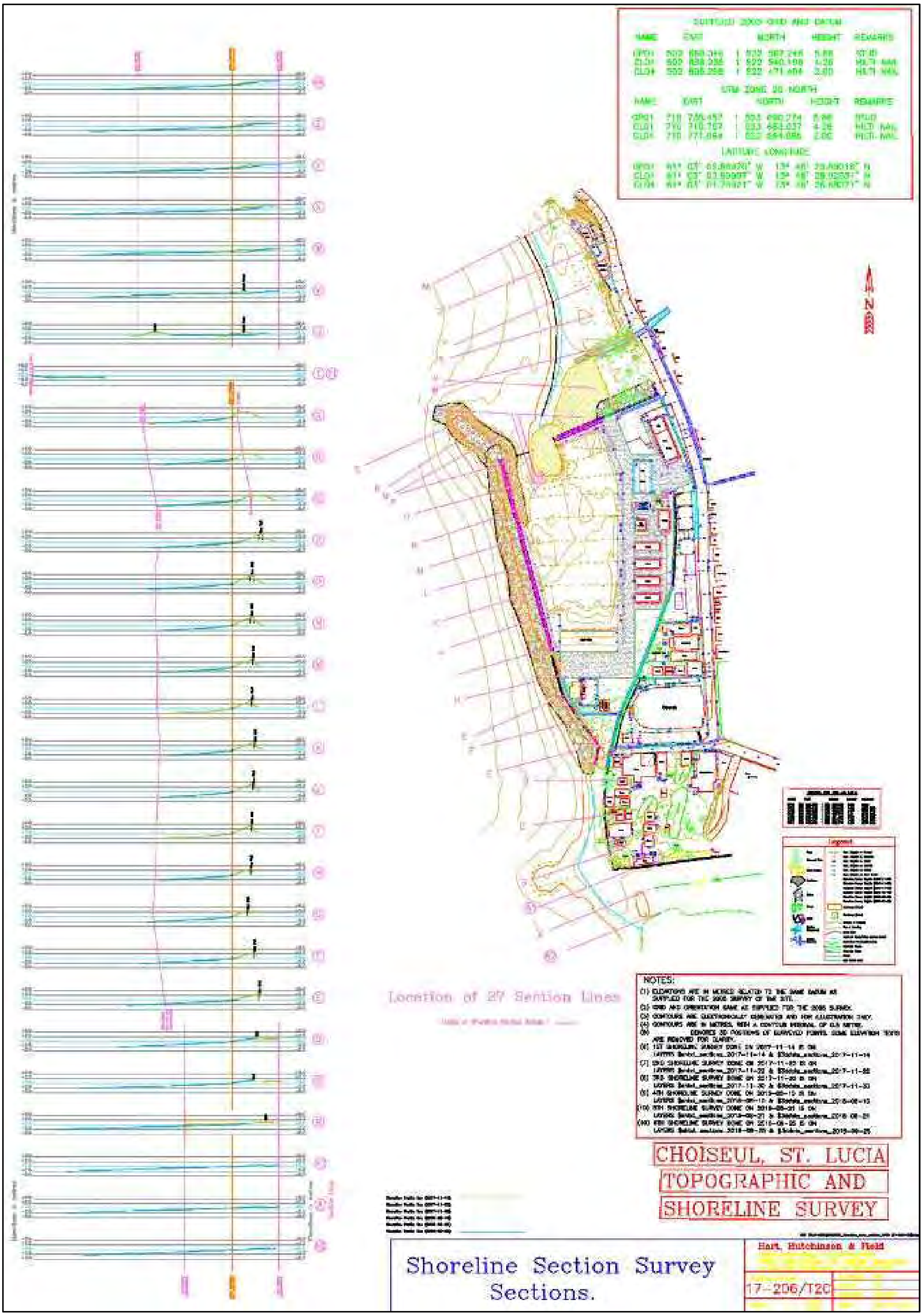


Figure 4-14 Shoreline survey (August and September, 2018)

4.6 Bathymetric Survey

Bathymetric survey was made in November 15 and 16, 2017 by Hart, Hutchinson & Field who was the local survey company. The results of bathymetric survey is shown in Figure 4-15.

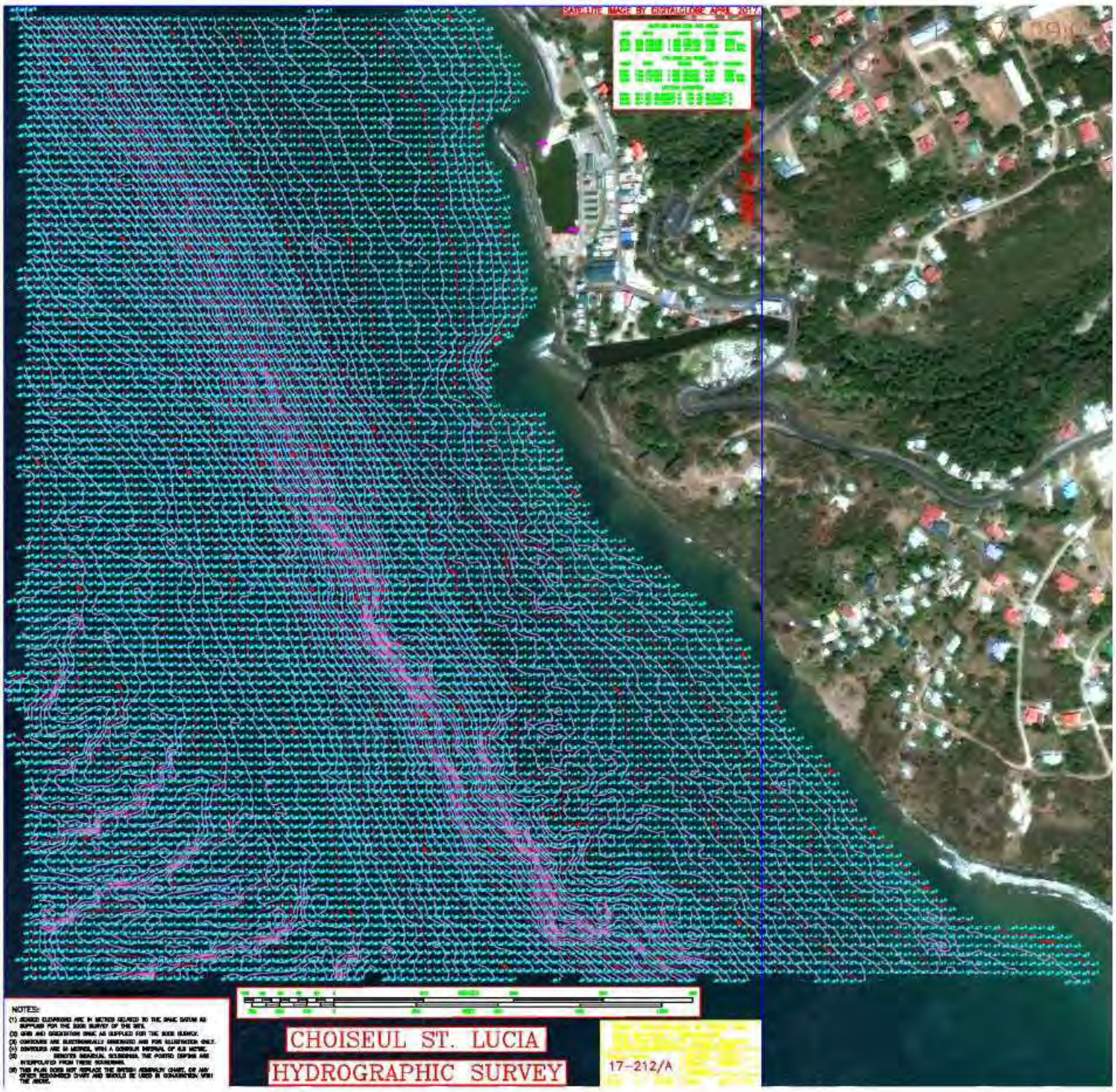


Figure 4-15 Bathymetric survey (November, 2017)

4.7 Sediment Survey

For understanding the sand features settled in Choiseul fishing port, grain size test, density test, gravel confirming investigation and mineral analysis were conducted collecting sands from bottom and beach on November 2017. Table 4-4 shows the content of sediment survey, and Figure 4-16 shows survey points. Figure 4-17 shows the sand density in each collecting point, and Table 4-5 shows median grain size obtained by particle size distribution test.

Table 4-4 Content of sediment survey

Survey	Test content	Collected point	No. of sample
Sediment A	Grain size and density tests	A-1～A-5(shoreline・2 samples in -2m)	10
Sediment B	Grain size and density tests	B-1～B-5	5
Sediment C	Gravel confirming test	C-1～C-4	—
Add survey	Mineral analysis by X-lay	A-5, B-5 upstream (2 samples in river bed and bank)	4

Figure 4-16 Sediment survey spot

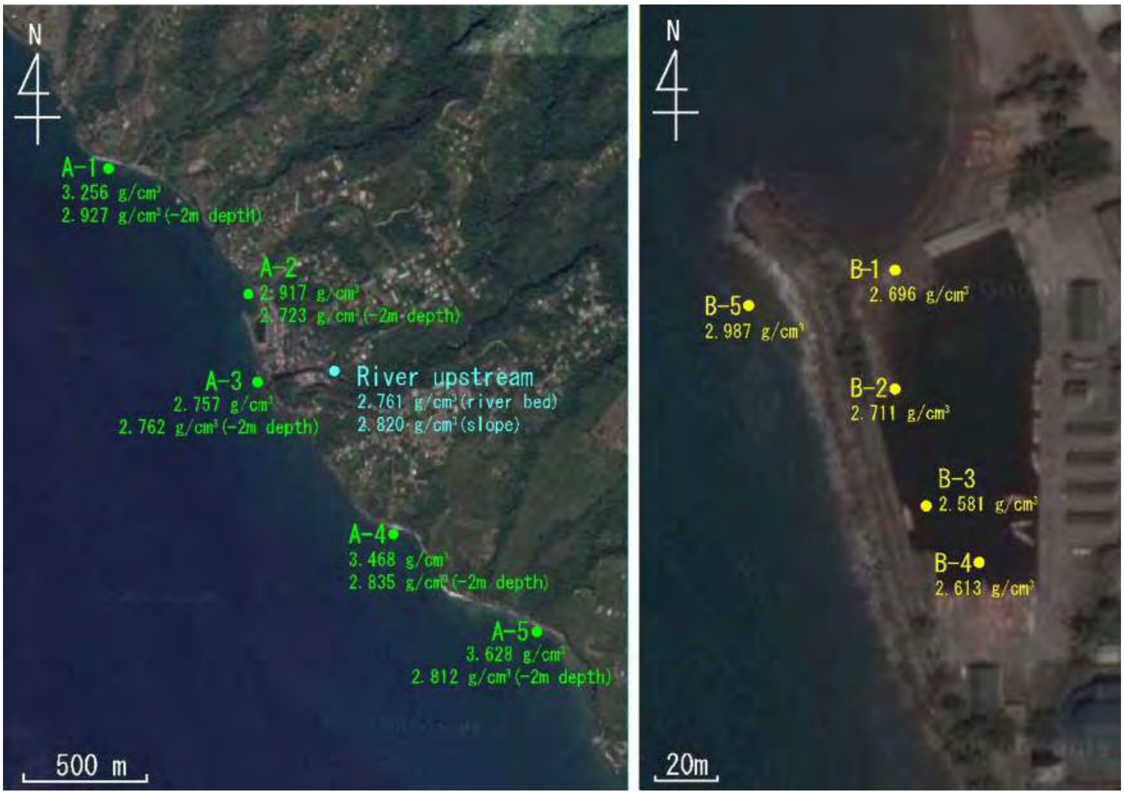


Figure 4-17 Sand density at each collected point

Table 4-5 Median diameter by grain size test (D_{50})

Location	At shoreline	At -2m depth
A-1	0.309mm	0.188mm
A-2	0.202mm	0.193mm
A-3	0.360mm	0.282mm
A-4	0.273mm	0.343mm
A-5	0.283mm	0.148mm
B-1	0.242mm	
B-2	0.190mm	
B-3	0.176mm	
B-4	—	
B-5	0.311mm	

4.8 Tide level

Tide level observation was carried out at the offshore of Choiseul fishing port for 1 month in August, 2000 reported in the existing data of “Report for basic design study of the project for improvement of coastal fisheries development in Saint Lucia (2011)”. Tidal level diagram near Choiseul by the harmonic analysis based on the site observation result is as shown in Figure 4-18.

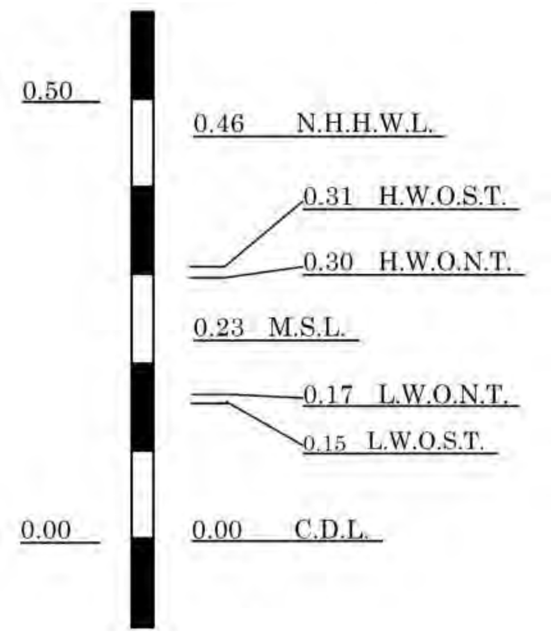


Figure 4-18 Tidal level diagram near Choiseul

Chapter 5　Wave hindcasting

Chapter 5 Wave hindcasting

5.1 Purpose

In this chapter, the results of wave hindcasting for 19 years (from 2000 to September 2018) in off the coast of Choiseul fishing port is presented. The project calculation flowchart is indicated in Figure 5-1 below.

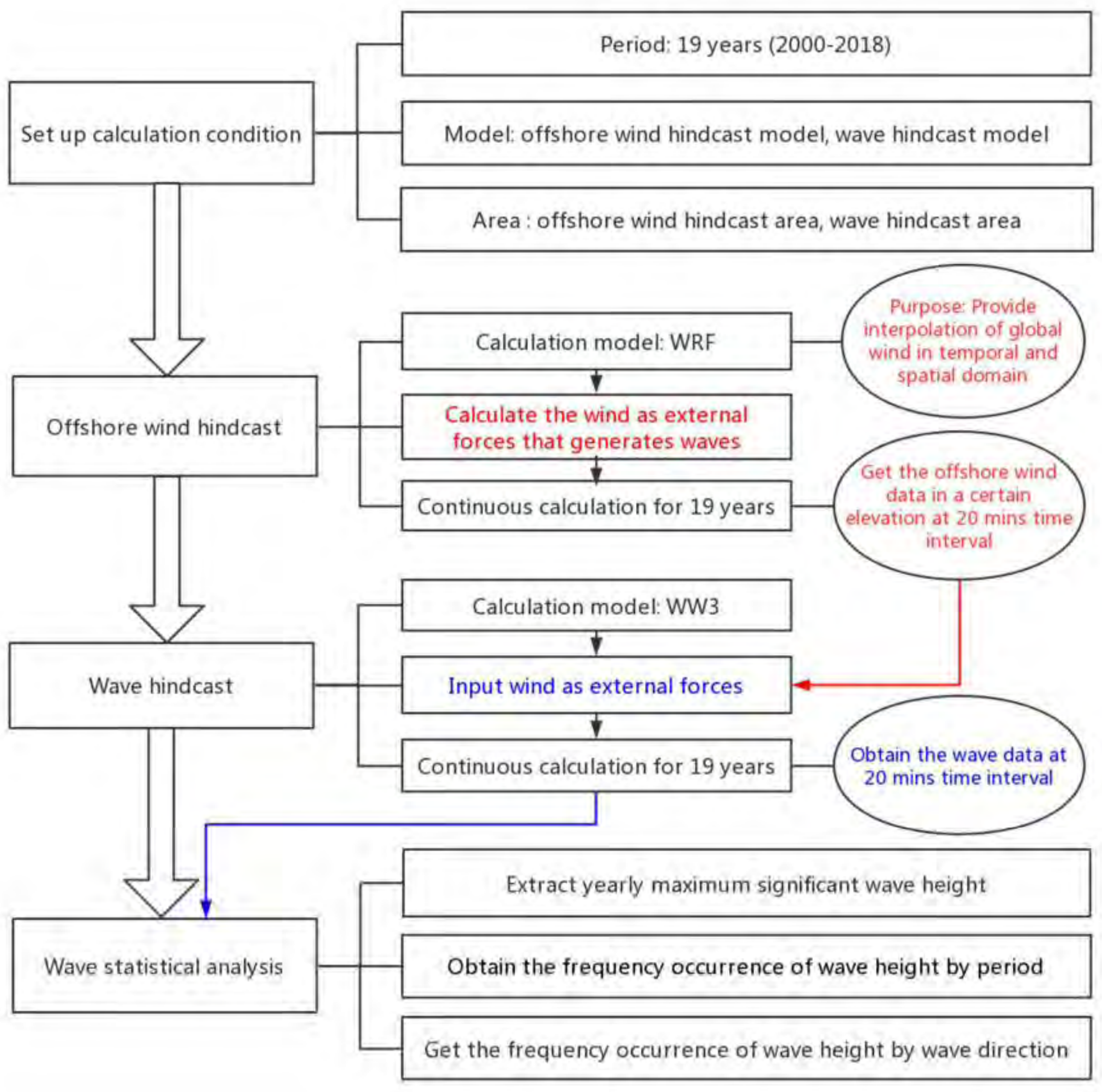


Figure 5-1 Calculation flowchart

5.2 Target Area

Saint Lucia is located in the Eastern Caribbean Sea on the boundary with the Atlantic Ocean. The target point (Choiseul) for the estimation of wave properties is located in the South-West coast of the island as depicted in the Figure 5-2 below. The approximate geographic coordinates of the selected location are,

- Choiseul : 61° 03' 05" W, 13° 46' 28.5" N

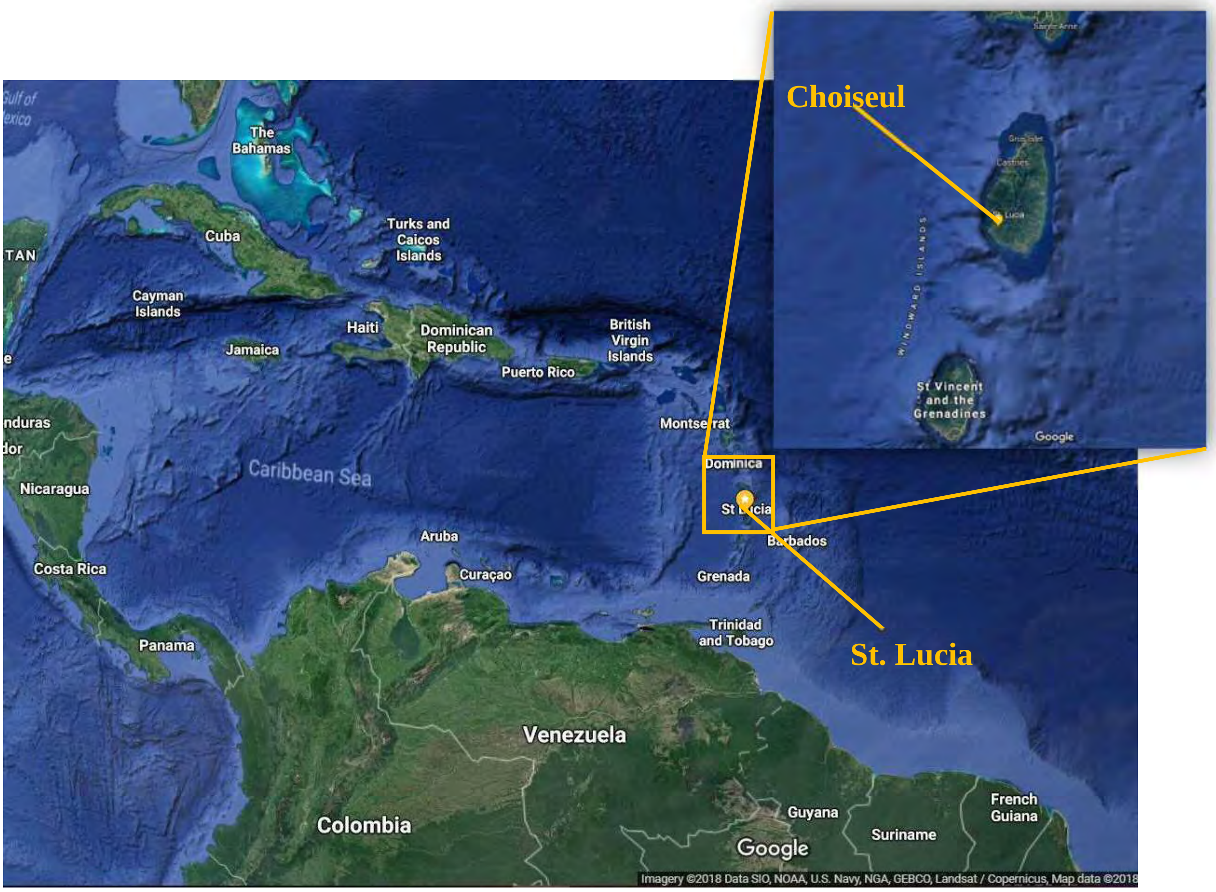


Figure 5-2 Target location on coastline of Saint Lucia

5.3 Estimation of Wind

The wind data which is required as an external input to run wave analysis were generated through 19-year (2000 to September 2018) analysis with weather model WRF. Different regional features (cities, forests, etc.) and topographic changes in the area were also incorporated in the calculation.

5.3.1 Numerical Model - Weather Research and Forecasting model (WRF)

Widely recognized numerical weather modelling programs were employed in the wave estimation process. WRF is capable of producing simulations based on actual or idealized atmospheric conditions, and has a worldwide community of users. The model is largely developed by National Center for Atmospheric Research (NCAR) of United States of America (https://www.mmm.ucar.edu/weather-research-and-forecasting-model). It is capable of simulating a number of physical phenomena such as flow over topography with various roughness, tropical cyclones, turbulent flows, etc. Also in Japan in recent years, WRF has been applied in cases related to heat islands, sudden heavy rainfalls, wind power generation, etc.

5.3.2 Analysis Condition and Input Data

5.3.2.1 Analysis condition

Table 5-1 shows the physical parameters and their conditions used in the WRF simulation. In this analysis, 35 layers in vertical direction from ground level up to 20hPa were set. The bottom layer was assigned with η=0.993 and layer thickness of 60 m. As a method of Four-Dimensional Data Assimilation (FDDA) in WRF nudging is adopted for the simulation, and standard sample value of 0.0003 was used as the nudging coefficient. Even though three different types of nudging are available in WRF as, (a) 3D analysis nudging, (b) 2D analysis nudging, and (c) observation nudging, only type (a) nudging was used in the present work. Moreover, when spatial resolution is 10km or less, calculation is done directly without the Cumulus parameterization. Results of the WRF analysis were outputted at every 20 min interval for all computational domain areas as a planar wind field.

Table 5-1 Calculation conditions of WRF

Physics	WRF variable	Scheme
Microphysics	mp	WSM 6-class graupel
Longwave Radiation	ra_lw	rrtm
Shortwave Radiation	ra_sw	Goddard shortwave
Surface Layer	sf_sfclay	Revised MM5 Monin-Obkhov
Land-Surface	sf_surface	thermal diffusion
Planetary Boundary Layer	bl_pbl	YSU
Cumulus	cu	Kain-Fritsch (only on 36/12km grid)

5.3.2.2 Input data

The estimation accuracy of the offshore wave directly depends on the accuracy of the wind data, and therefore it is necessary to acquire accurate wind data in the best possible resolution in both space and time. JRA-55 is one such reanalysis project conduct by Japan Meteorological Agency (JMA) to support climate research and services with high quality dataset with homogeneity in both space and time. In contrast to the previous projects of JMA, JRA-55 has improved in model resolution, data assimilation scheme, and in the quality of data observation sources. Therefore, JRA-55 was used as the source of wind data for the current project.

However, due to the unavailability of JRA-55 reanalysis data for the year 2018, the NCEP (National Centers for Environmental Prediction) FNL ds083.2 Operational Global Analysis data are used as the wind input for WRF simulation.

- JRA-55

Period (used in current project)	: January 1, 2000 - December 31, 2017
Scope	: Globe
Spatio-temporal resolution	: 6hour interval, 1.25 ° interval (latitude and longitude mesh)
Related information	: http://www.jmbsc.or.jp/jp/offline/hd0020.html

- NCEP FNL ds083.2

Period (used in current project)	: January 1, 2018 - September 30, 2018
Scope	: Globe
Spatio-temporal resolution	: 6hour interval, 1° intervals (latitude and longitude mesh)
Related information	: https://rda.ucar.edu/datasets/ds083.2/

5.3.3 Area of Computation

Figure 5-3 to 5-5 below show the outlines of topographic domains used in wind calculations. In order to closely capture the change in physical properties in the numerical simulation, sub-domains with finer grid resolutions are nested inside the larger domain. Wind calculation domain was selected in such a way that it covers whole wave calculation domain which uses the wind output of WRF for wave analysis. Table 5-2 shows the grid size of WRF simulation domains.

The topographic and land usage data required in the setting of calculation area were assigned using USGS GTOPO30 elevation data set and USGS 24 category land data set, respectively. In addition, ds 090.0 data were used for the temperature and moisture of soil.

The planer view of the wind field estimated from the WRF computation for finer domain area is shown in Figure 5-3 (only for some selected time-steps). From the figures, it is visible that the effect from the mainland of Saint Lucia on the wind field is well represented in the simulation.

Table 5-2 Grid size of domains

Domain No.	Grid Size
0	0.5°
1	36.45km
2	12.15km
3	4.05km
4	1.35km

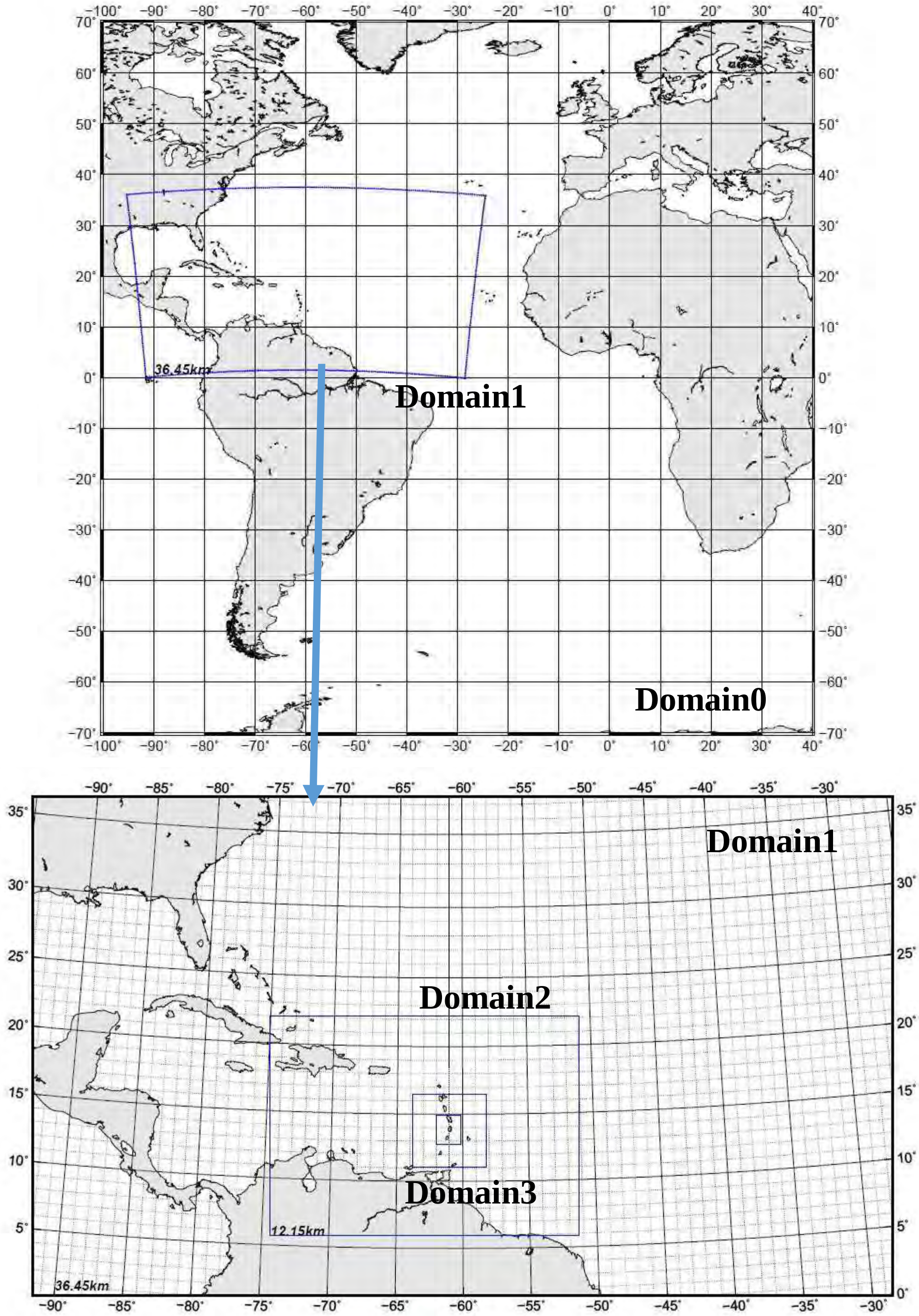


Figure 5-3 Calculation domains for WRF (Domain0: top Domain1: bottom)

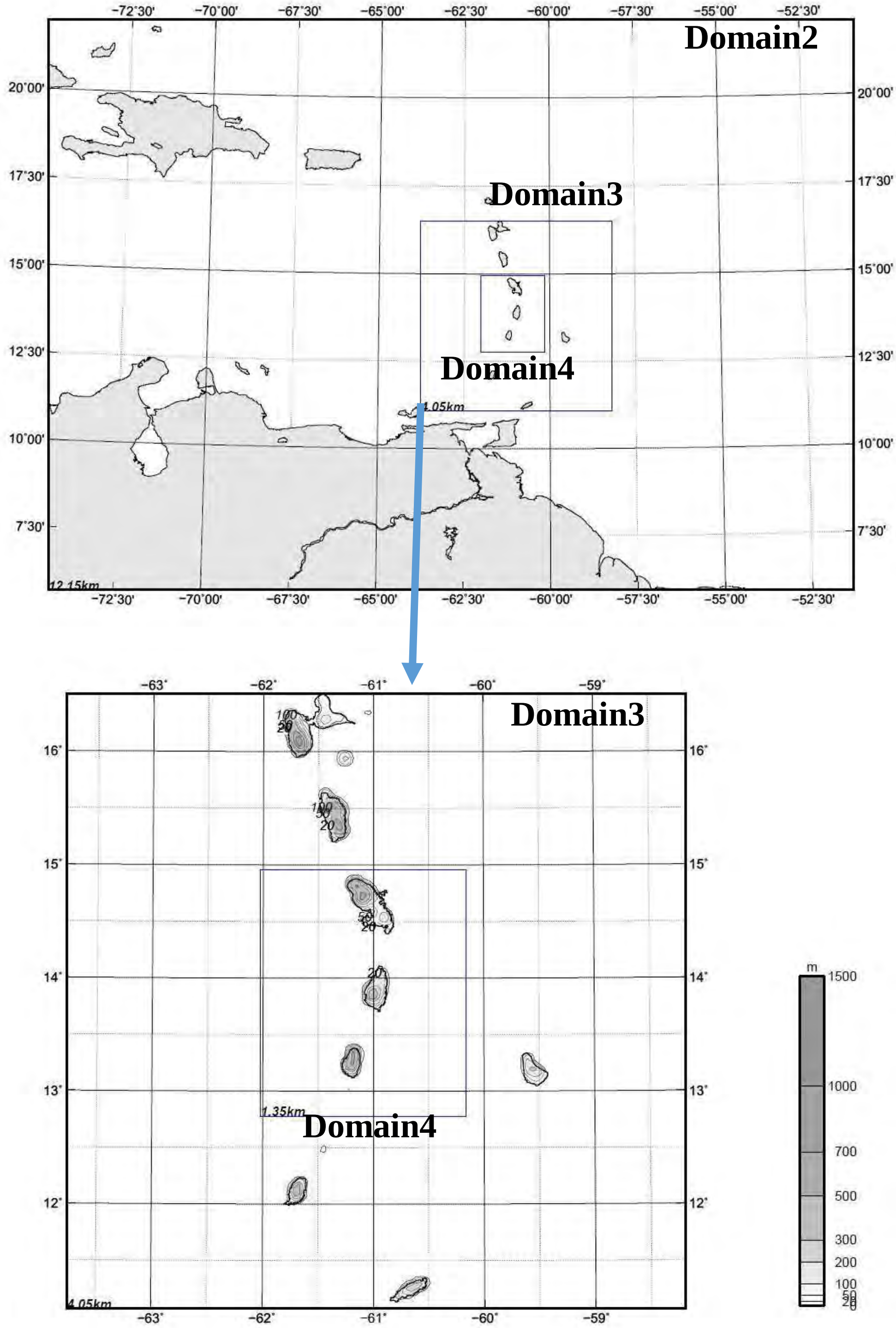


Figure 5-4 Calculation domains for WRF (Domain2: top Domain3: bottom)

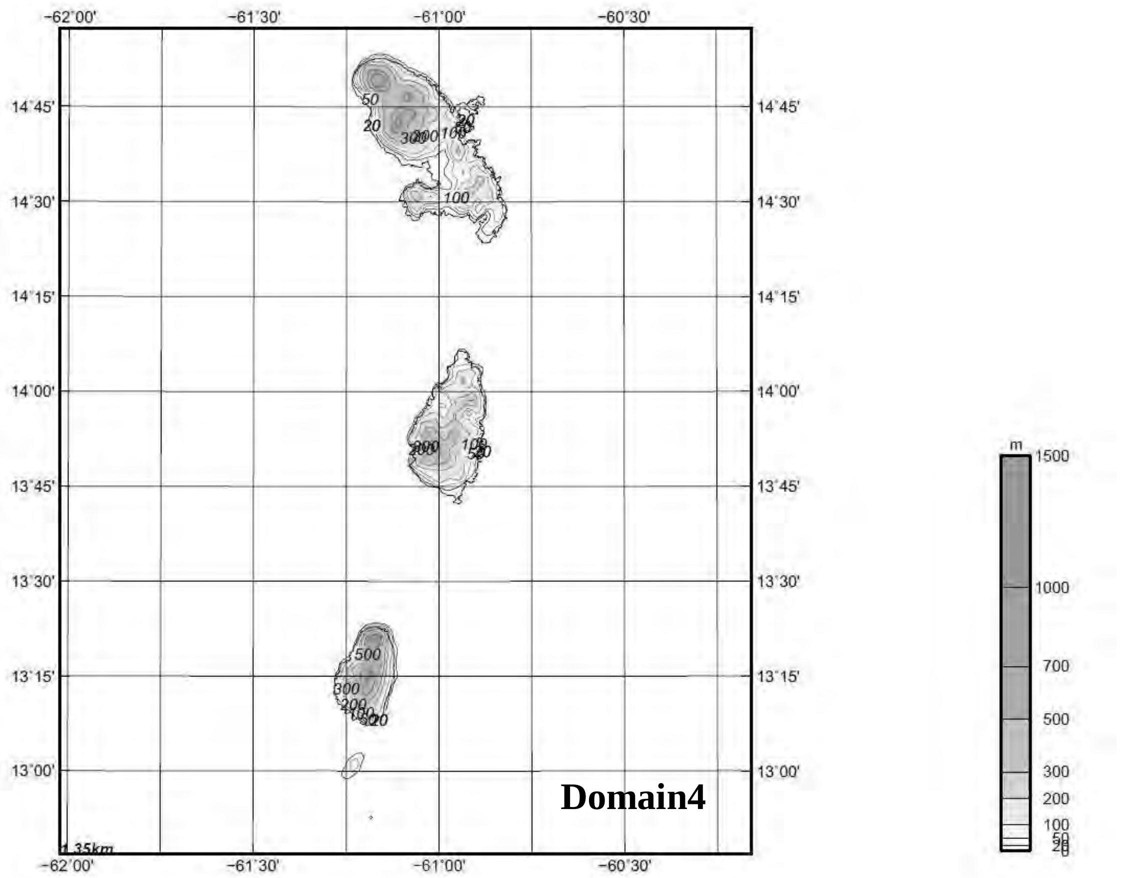


Figure 5-5 Calculation domains for WRF (Domain4)

5.3.4 Sample of Simulation Results

As an example of offshore wind estimated by WRF, the planar wind speed distribution and wind direction is shown below for following time steps in Figure 5-6~5-7.

- 2016 Sep. 29 00:00
- 2016 Oct. 01 00:00
- 2017 Dec. 06 12:00
- 2017 Dec. 12 12:00

The locations of Choiseul fishing port (wave data collection location) and Hewanorra (wind observation data collection location) are marked with red circles on the figure. It is evident from the figure that the wind speed from Atlantic Ocean is reduced under the effect of main land of Saint Lucia. Such planar wind field (containing wind speed and direction) were generated for every 20 min interval for 19-year period (2000 to September 2018).

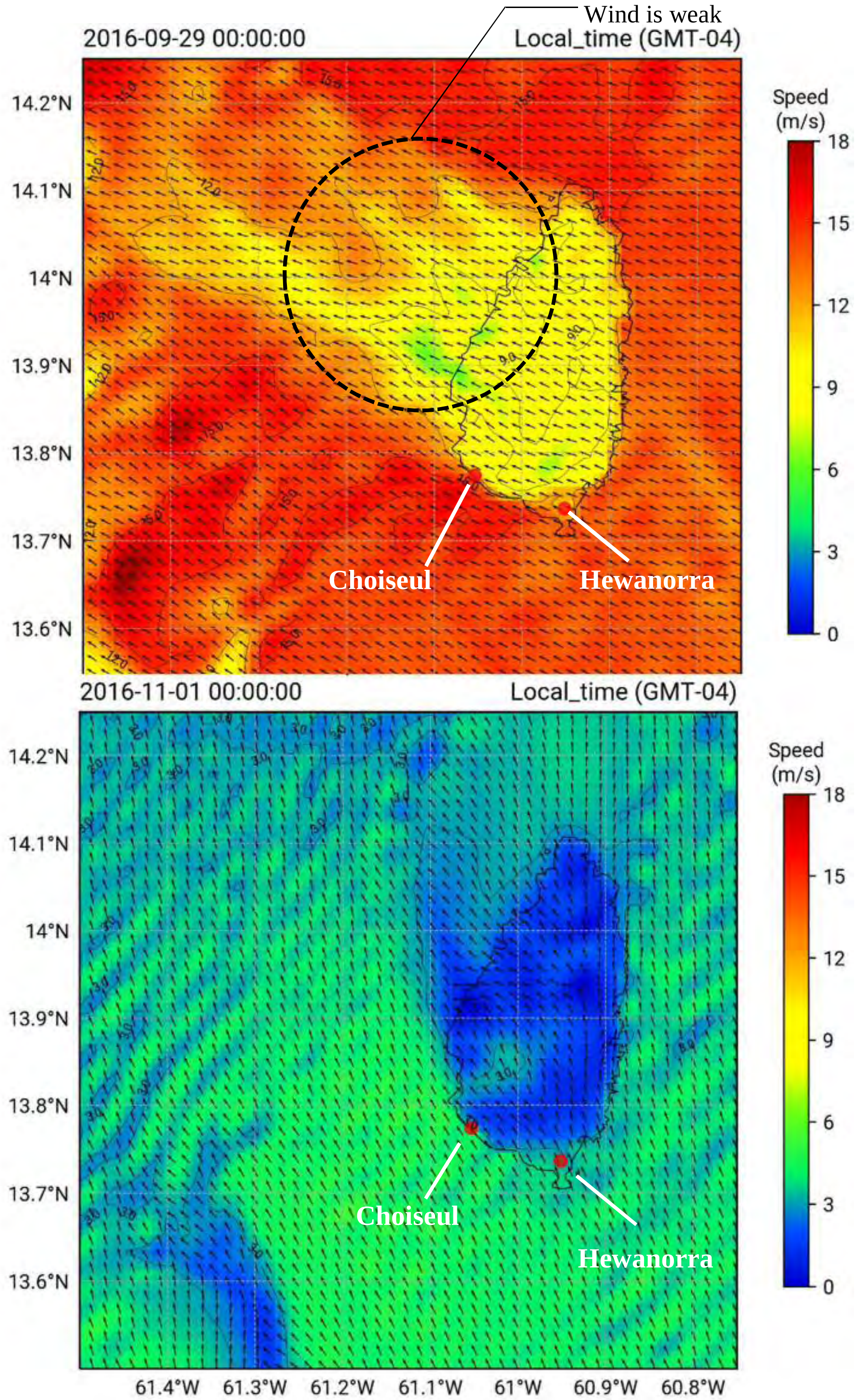


Figure 5-6 Plan view of WRF calculated results (wind speed and direction) at selected time steps

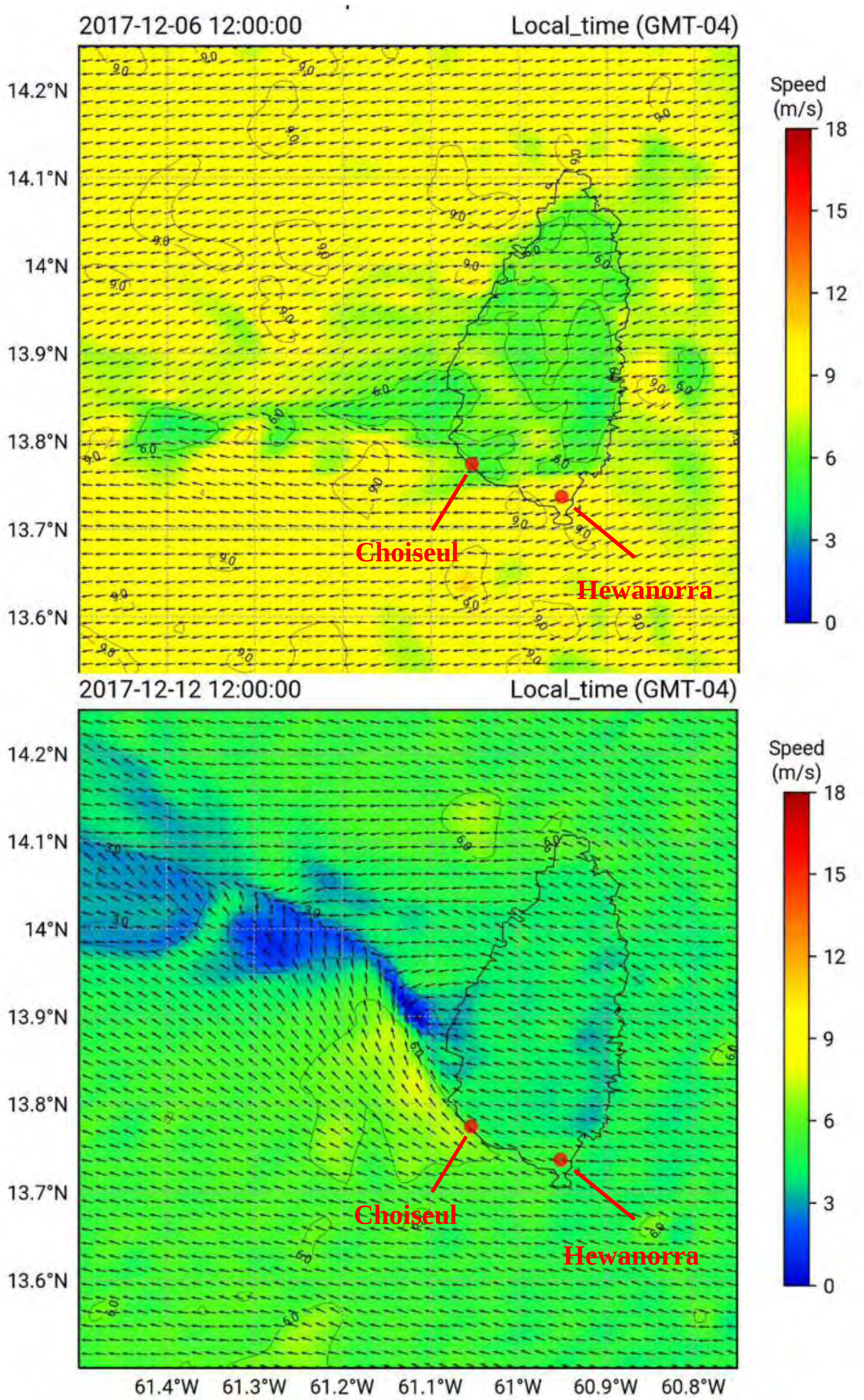


Figure 5-7 Plan view of WRF calculated results (wind speed and direction) at selected time steps

5.3.5 Comparison with Observation Data

Observation data of wind are available from year 2003 to 2018 at the data collection station located in Hewanorra (South-East of Choiseul fishery harbor). Figure 5-8 shows the comparison of temporal variation of wind speed and direction between observation (blue) and WRF simulated results (red) for year 2016, 2017 and 2018. Rest of the comparisons is presented in the Annex.

As it can be seen from the Figure 5-8 wind speed is well reproduced by WRF simulation. However, for year 2018 simulated wind speed is slightly lower than the observation. Since, FNL ds 083.2 reanalysis data were used for 2018 WRF simulation (JRA-55 data were used for the rest of the years), it is apparent that JRA-55 reanalysis data leads to better outcome in WRF analysis than with FNL ds 083.2 reanalysis data. The exact reason for the difference between two reanalysis data is unclear.

In addition, the wind direction comparison does not show significant difference over the years. However, the simulated wind direction seems to be slightly shifted toward 'E' direction in comparison to the observation. Since the simulation was conducted with minimum grid size of 1.35 km, it is unlikely to get highly accurate wind direction as outcome. This can be one of the major reasons for the slight deviation as topographic data is highly influential in wind direction.

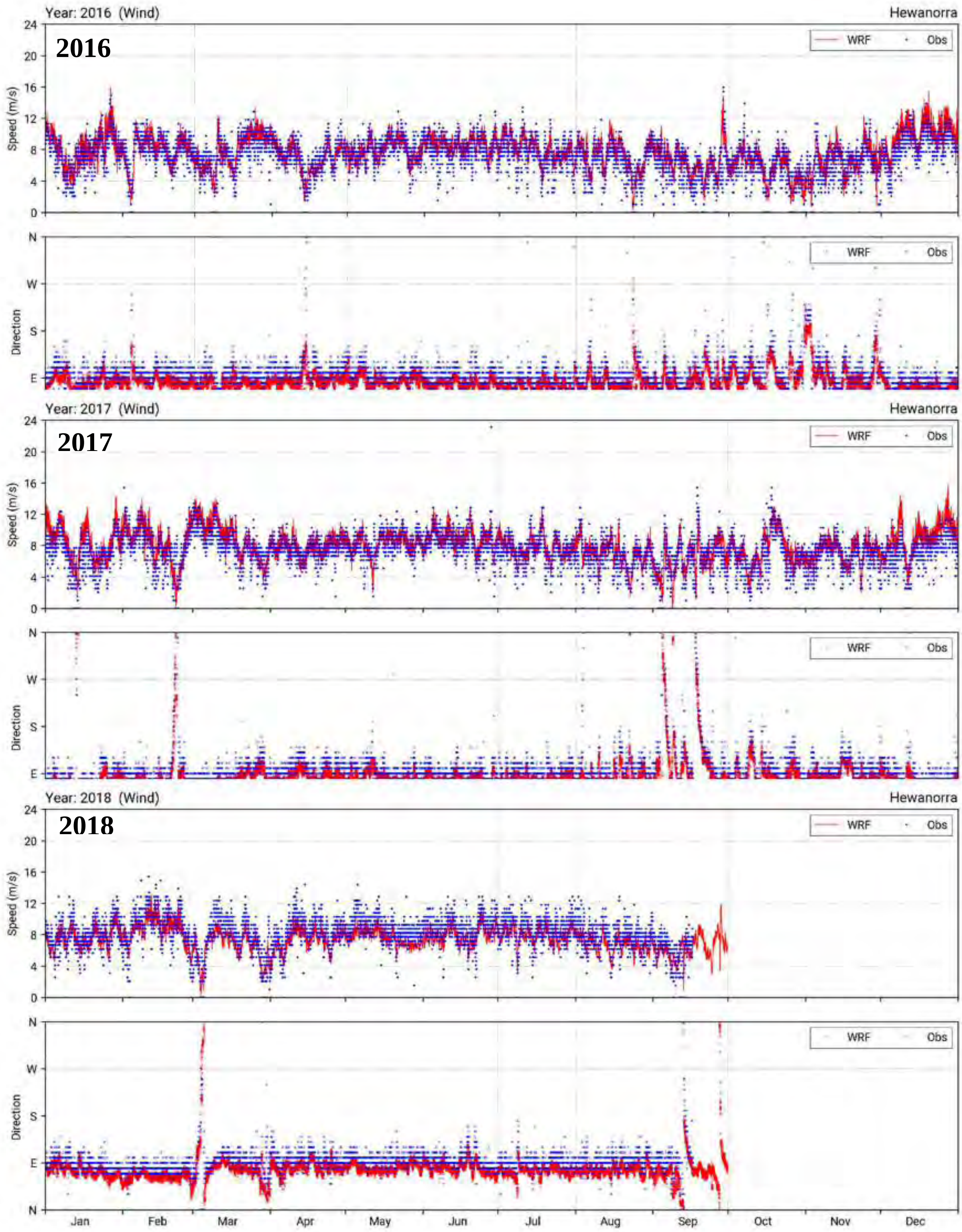


Figure 5-8 Wind speed and wind direction for year 2016, 2017 and 2018; comparison of observation (blue) and WRF simulated results (red).

5.4 Wave Hindcast

The Wave Watch III (WW3) model was chosen as the simulation model for 19-year wave estimation. The simulation was conducted from year 2000 to September 2018, and the wave parameters were obtained near Choiseul fishing port at 20 min interval.

5.4.1 Wave Model – Wave Watch III (WW3)

WW3 (Wave Watch III) is a third-generation wave model developed in cooperation of NOAA and NCEP. In recent years, it is generally used in the United States of America and Japan as well. In Japan, referenced document below in which technical standards for designing port facilities are stipulated introduces the model for wave considerations.

- TECHNICAL STANDARDS AND COMMENTARIES FOR PORT AND HARBOUR FACILITIES IN JAPAN (May 2018)
  The Ports and Harbours Association of Japan, under the supervision of Ports and Harbours Bureau, Ministry of Land, Infrastructure, Transport and Tourism

5.4.2 Calculation Condition

Table 5-3 shows the calculation conditions of WW3 used in this work. The calculation conditions are based on the standard setting of WW3.

Table 5-3 Calculation condition of Wave Watch III

Description		Value/Method
Parameters of wave spectra	Num. of directions	36 ($\Delta\theta = 10^0$)
	Num. of frequencies	25 (2.5s – 24.3s)
Input and dissipation source terms		ST2 (default parameters in WWIII v 5.16)
Switch parameters (WWIII manual v 5.16)	Propagation scheme	PR3
	Nonlinear interactions	NL1
	Bottom friction	BT1
	Depth induced breaking	DB1

5.4.3 Area of Computation

Since Saint Lucia is on the boundary with the Atlantic Ocean, the East-coast of the island exposed to the open sea. Therefore, a larger area including the Atlantic Ocean was included in the largest computational domain in order to account for the effect of wind generated waves from all directions.

Figure 5-9 to 5-14 below shows the outlines of topographic domains used in wave computation. Wind output from the WRF is projected on to these domains as an external source for wave generation. In order to closely capture the change in physical properties in the numerical simulation, sub-domains with finer grid resolutions are nested inside the larger domain. M.S.L. is adopted as a tide condition.

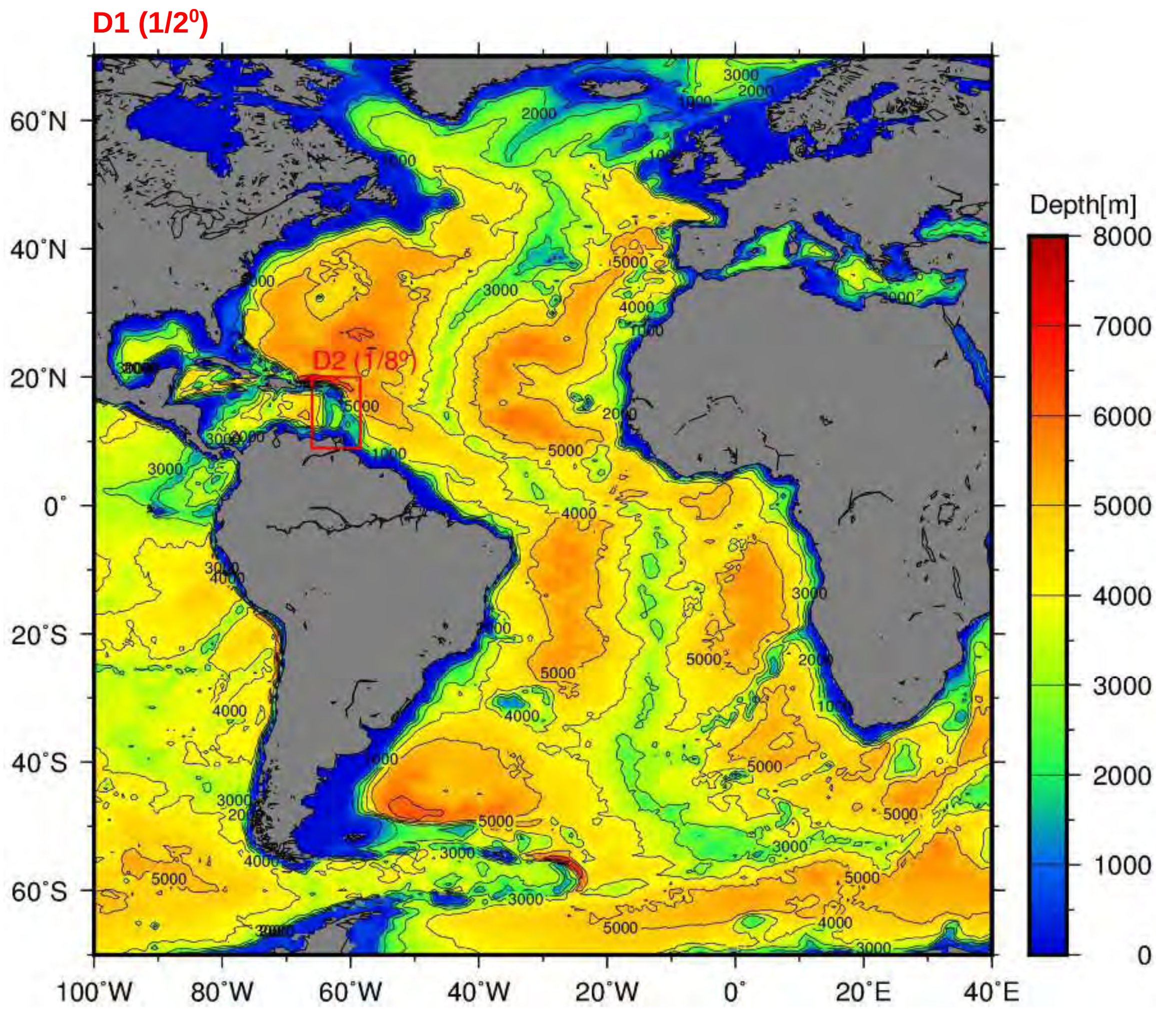


Figure 5-9 Calculation domains for wave analysis (Domain1: grid resolution - $1/2^0$)

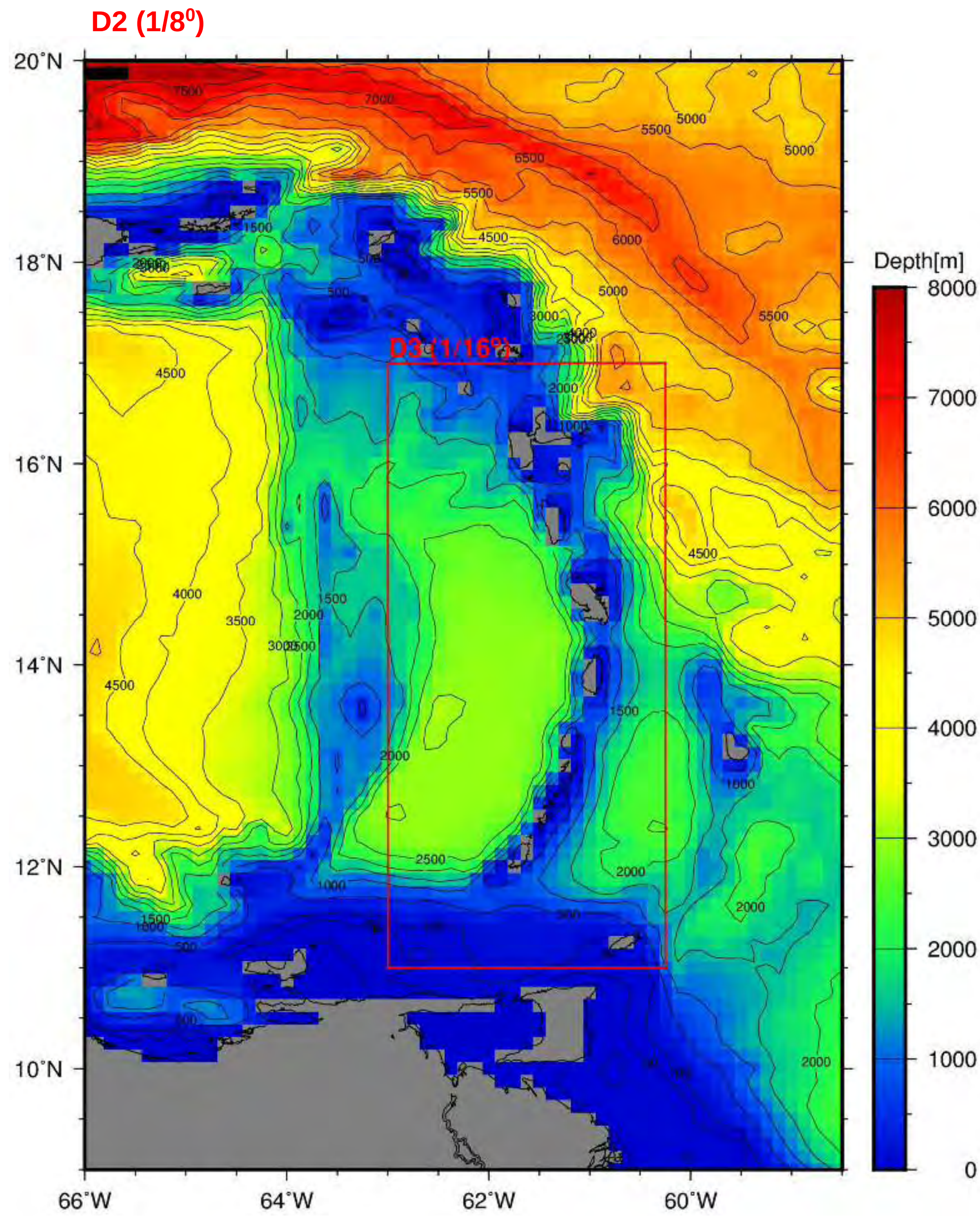


Figure 5-10 Calculation domains for wave analysis (Domain2: grid resolution - $1/8^{0}$)

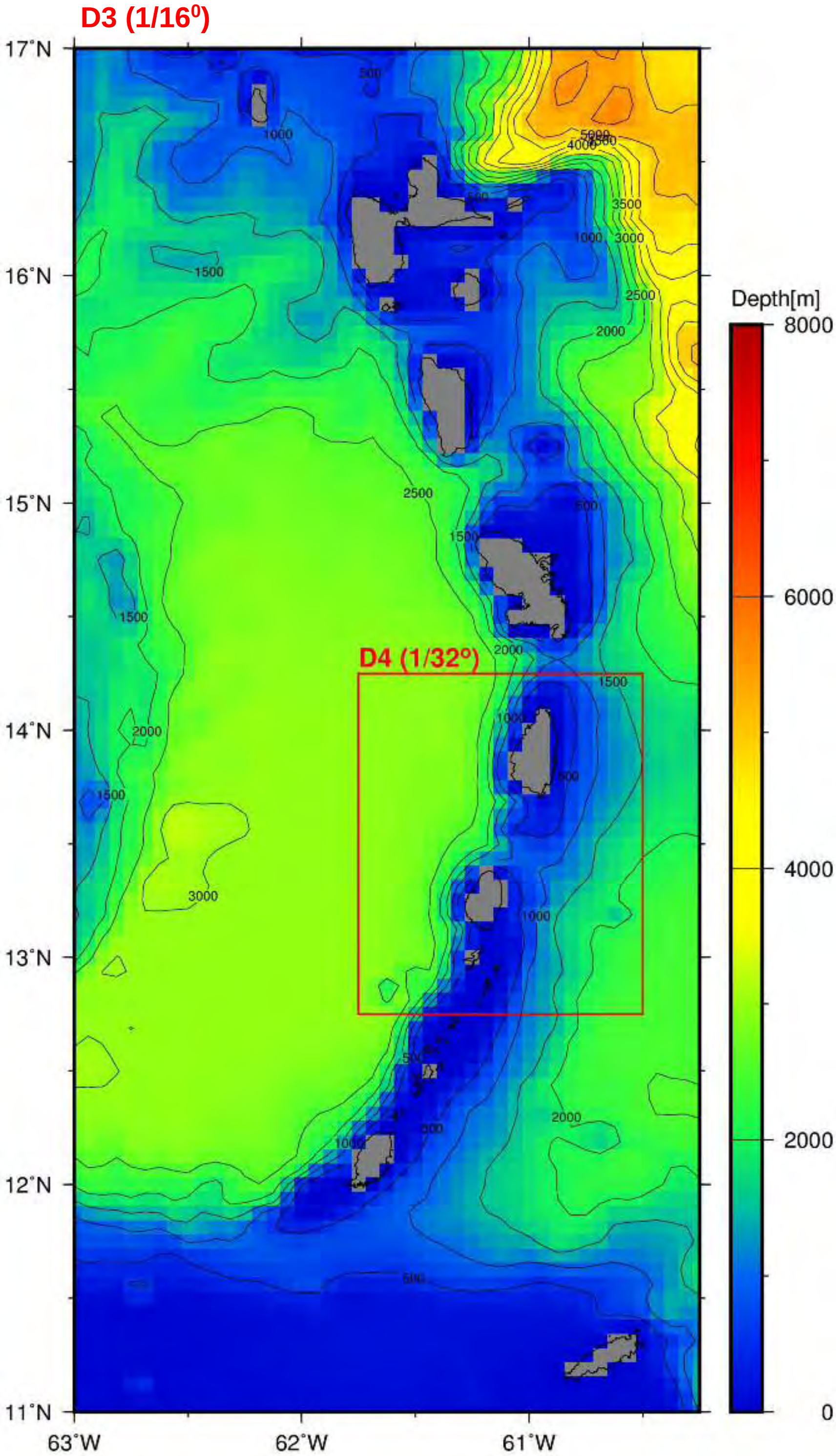


Figure 5-11 Calculation domains for wave analysis (Domain3: grid resolution - 1/16^0)

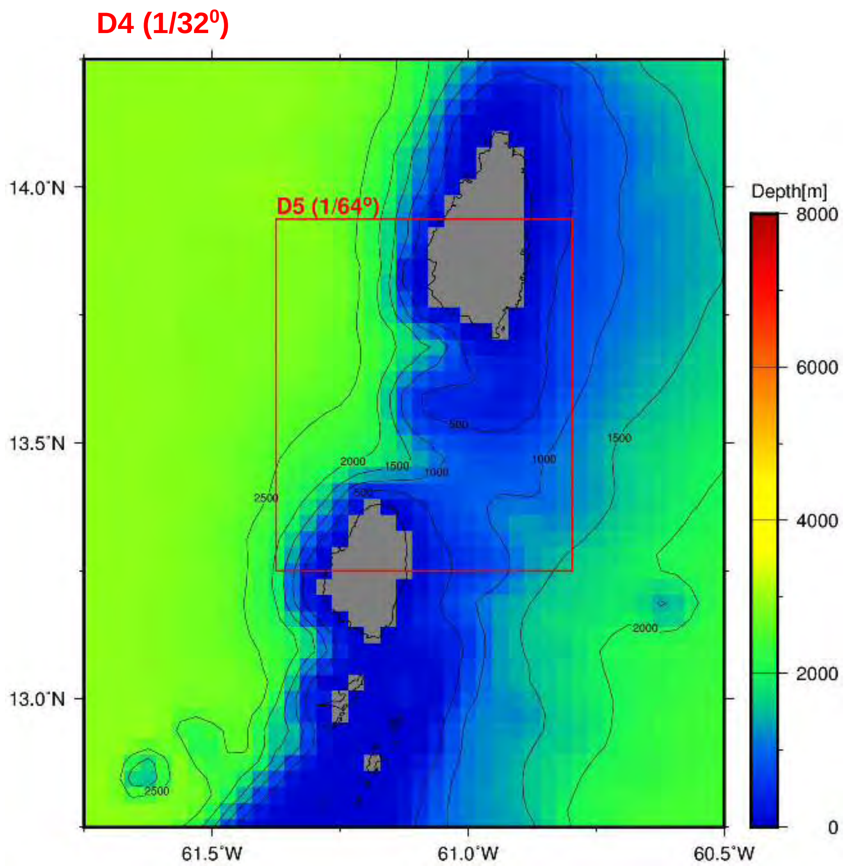


Figure 5-12 Calculation domains for wave analysis (Domain4: grid resolution - $1/32^0$)

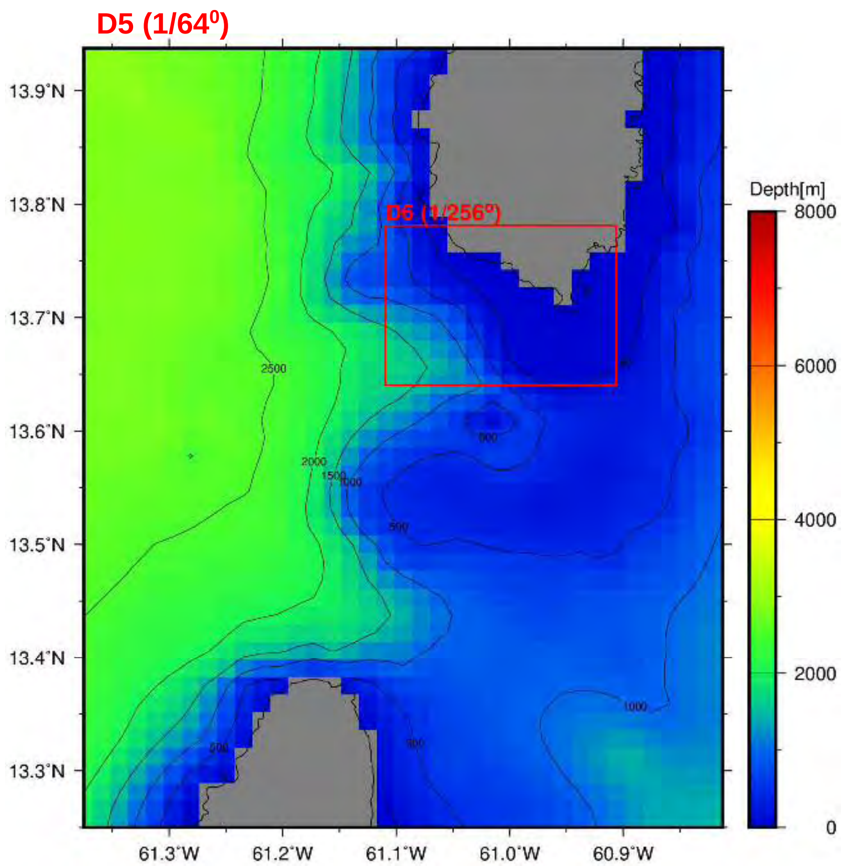


Figure 5-13 Calculation domains for wave analysis (Domain5: grid resolution - $1/64^0$)

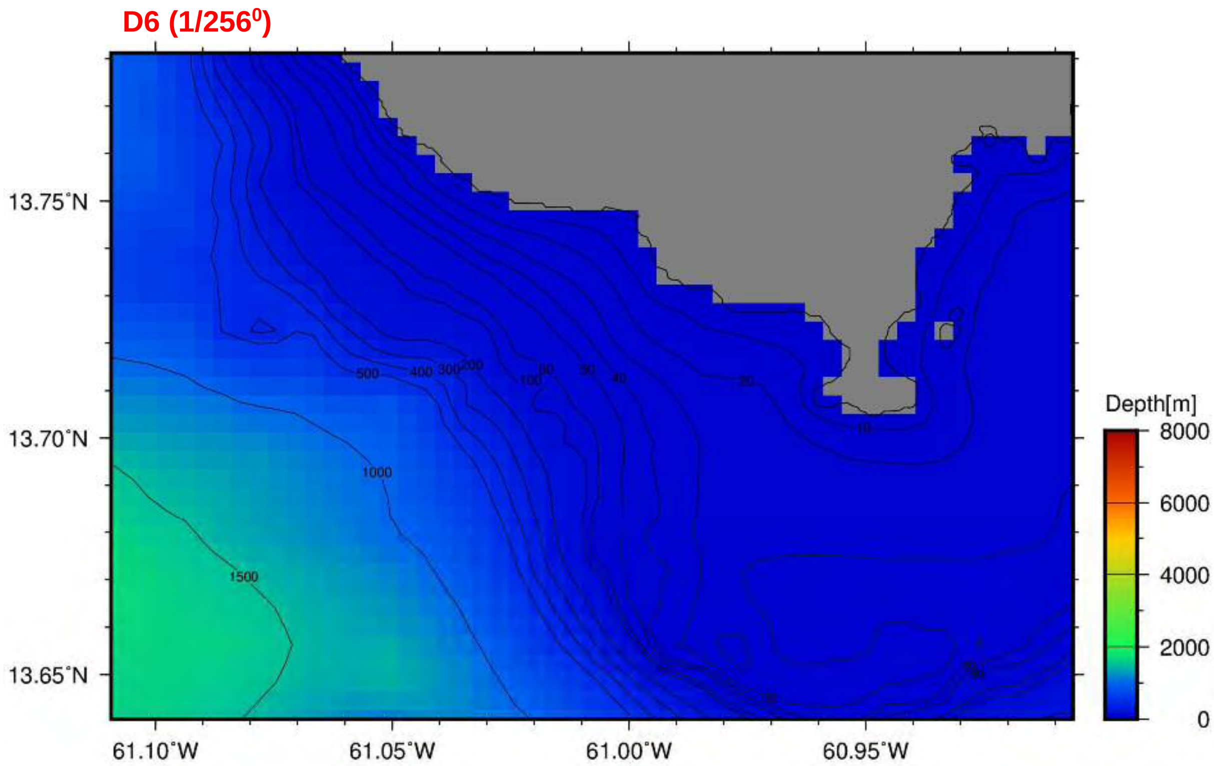


Figure 5-14 Calculation domains for wave analysis (Domain6: grid resolution - 1/256^{0})

5.4.4 Sample Simulation Results

The planer view of the significant wave height distribution and wave direction around Choiseul calculated from the WW3 simulation is shown in Figure 5-15 and 5-16 (for the smallest domain, Domain6) at 4 time steps below.

00:00 on 29 September, 2016
00:00 on 1 November, 2016
12:00 on 6 December, 2017
12:00 on 12 December, 2017

It can be noted that most part of the year wave approaches Saint Lucia from the Atlantic Ocean and get refracted by the shallow bottom before reaching the coasts of Choiseul.

As a result of the simulation such planar wave height and direction distribution data were generated for whole 19-year period (2000 to September 2018) at 20 min interval.

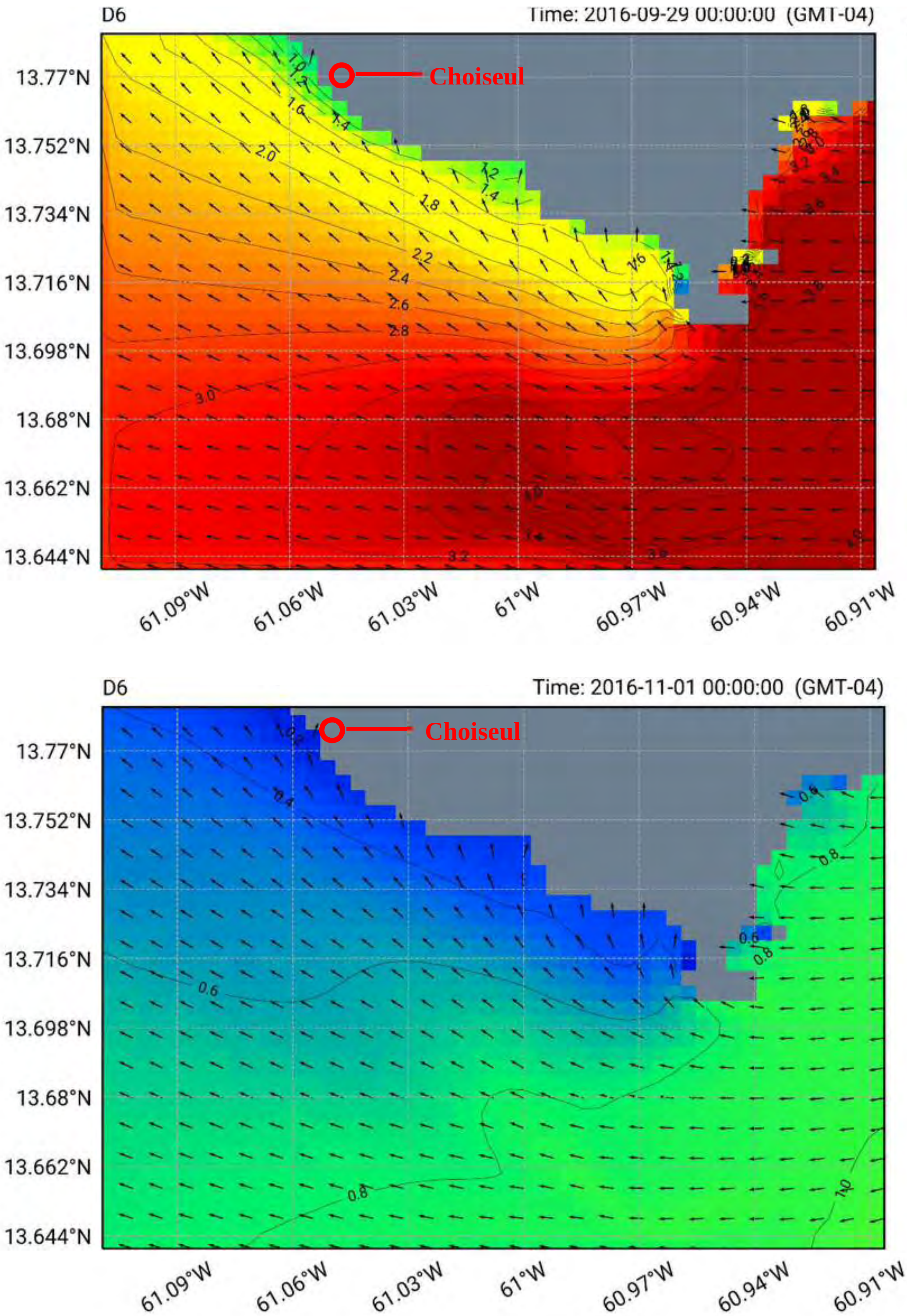


Figure 5-15 Plan view of WW3 computed results (wave height and direction) at selected time steps

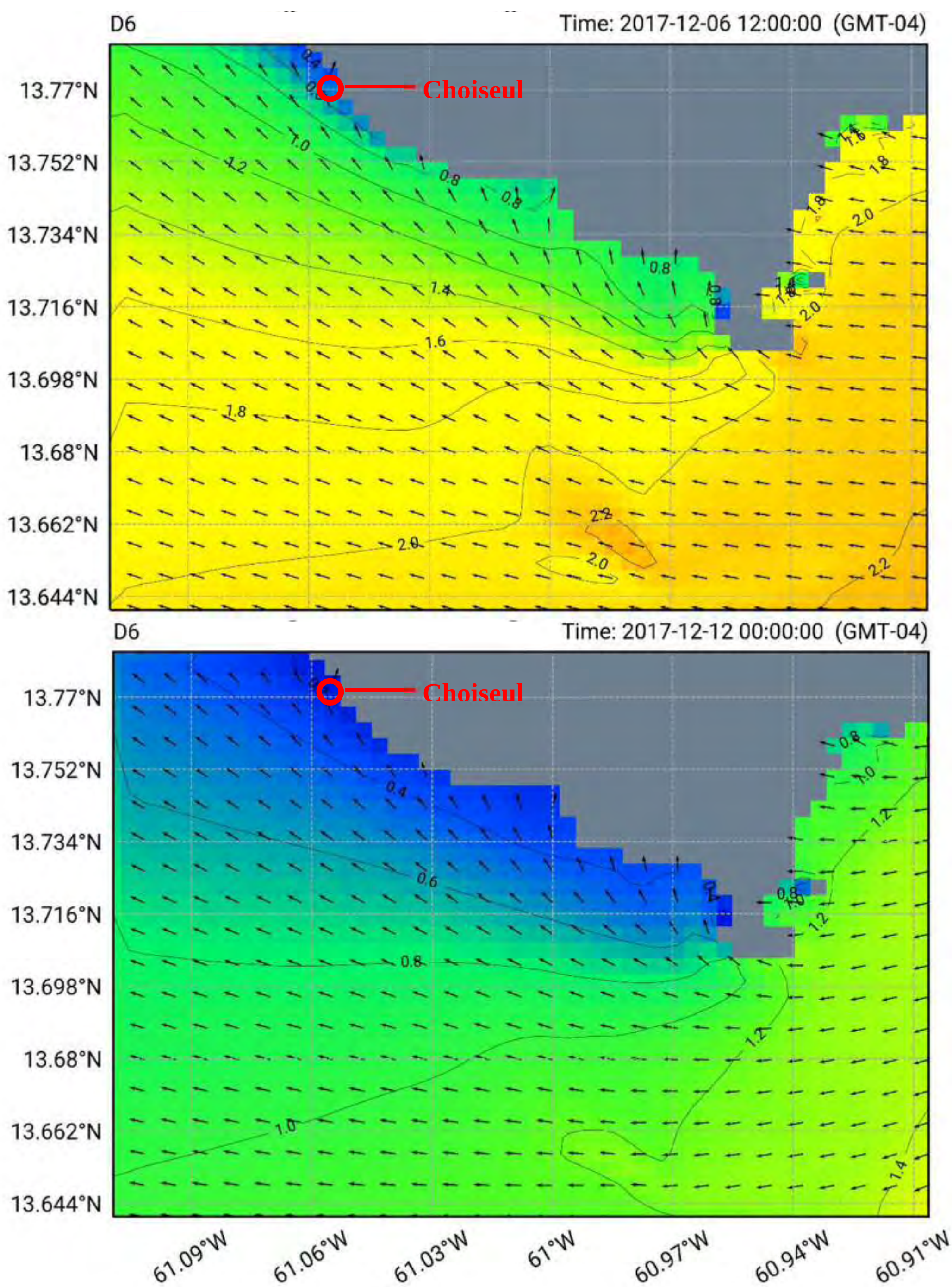


Figure 5-16 Plan view of WW3 computed results (wave height and direction) at selected time steps

5.4.5 Confirmation of Calculation Accuracy

In order to validate the estimated wave properties (significant wave height, wave period, and wave direction) from WW3, those estimated properties with observation data in offshore of Choiseul fishing port are compared. Wave observations were conducted in year 2017 and 2018. Figure 5-17 shows the comparison of WW3 results with observation for significant wave height, wave period, and wave direction during the observation period. In the figure, blue circles represent the observations while red line indicates the estimated value.

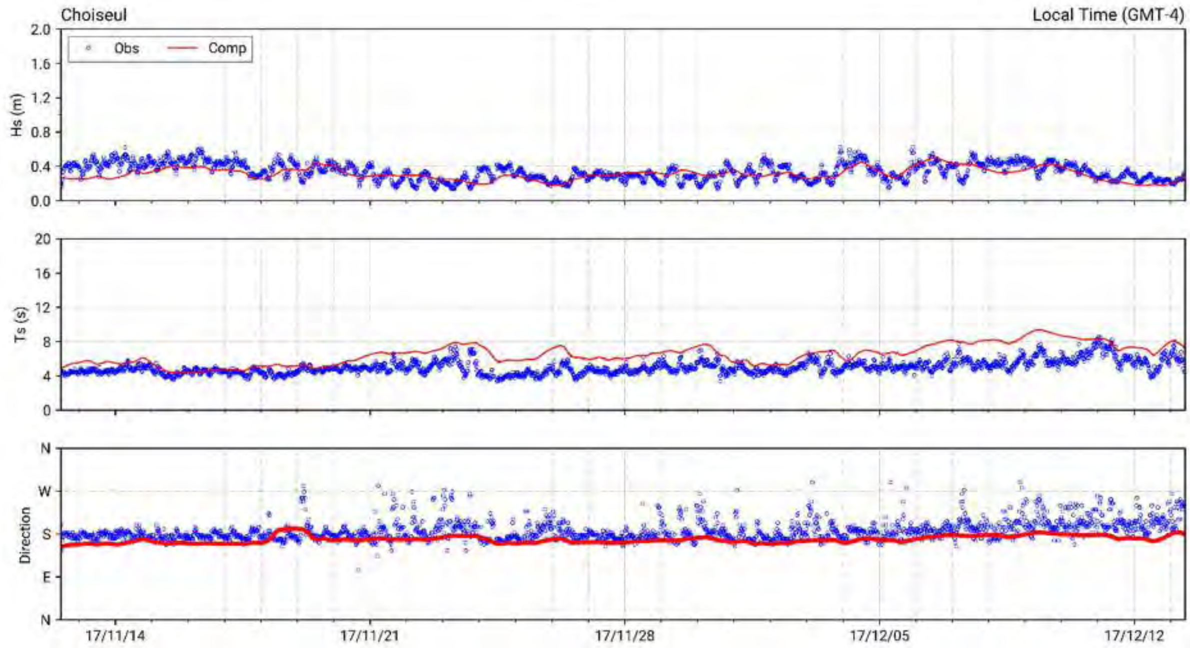
Although, the wave height reproduced well for year 2017, the estimated values are slightly smaller than the observed value for year 2018. This occurs because of the change in wind source data for year 2018. Up to year 2017 JRA-55 reanalysis wind data were used as surface wind input which needed to generate waves, and due to the unavailability of the JRA-55 data, year 2018 WRF simulation was conducted with FNL ds 083.2 wind reanalysis data. As seen from Figure 5-18, the estimated wind speed by WRF when FNL ds 083.2 wind data is used, tend to be slightly weaker than the observations. Consequently, reduces the wave height as well.

Moreover, the observation wave height shows a fluctuation which occurs twice a day, while a similar pattern cannot be observed with WW3 estimated data. Such fluctuations are assumed to be occurred due to the tidal effect. However, water depth change due to tidal fluctuations were not taken into consideration in the wave simulation. In addition, the estimated wave direction does not differ much between year 2017 and 2018, and shows a good agreement with the observations. The slight difference between observed and estimated wave directions can occur due to the effect of wind waves generated under local wind field.

Figure 5-18 shows the correlation analysis of observed and estimated wave heights. In the figure, for year 2017, it can be noted that the estimated wave height is somewhat smaller than the observed wave height. This is considered to be one of the reasons that the observation wave is influenced by the local wind field. From the lower part of the Figure 5-18 (year 2018), estimated wave height underestimates the observations, especially at low wave heights. This is because, the estimation accuracy of the offshore wind field is weak for year 2018 (Figure 5-8).

Considering above factors following statement can be made regarding the accuracy of the simulation results.

- Wind data estimated by WRF using JRA-55 reanalysis data as input has a sufficient accuracy when compared with the observation wind data. Wave analysis results estimated with WRF wind output with JRA-55 data input also shows a good agreement with observation data. Therefore, wave analysis carried out from 2000 to 2017 also has a sufficient accuracy.



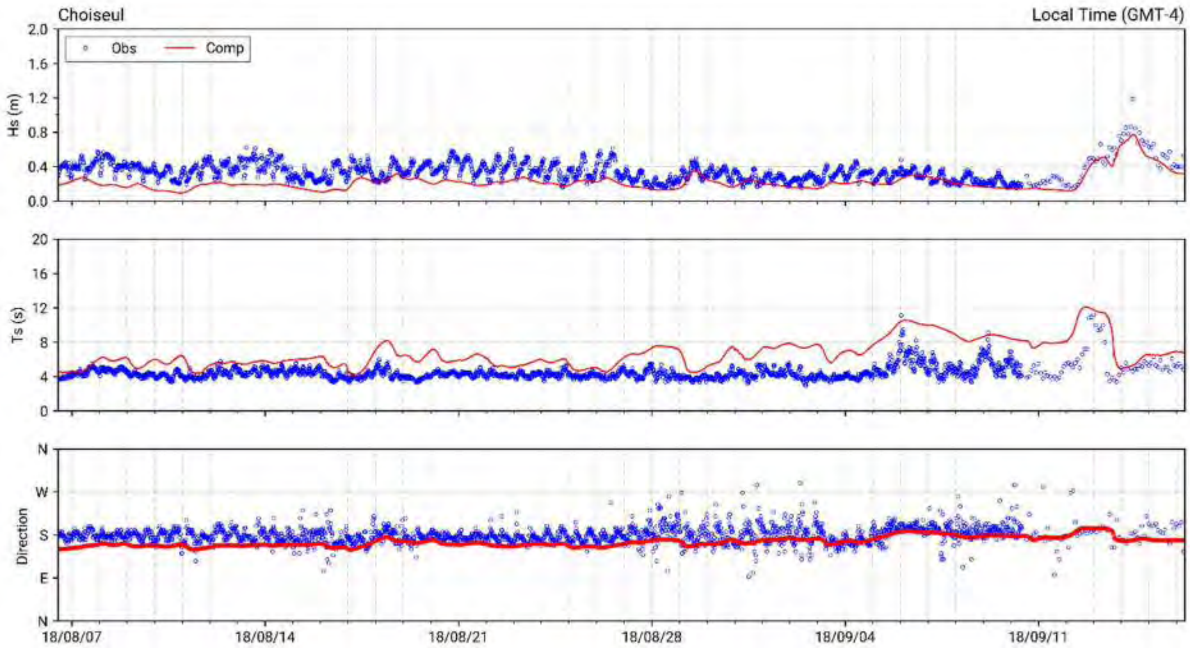


Figure 5-17 Comparison of observation (blue) and WW3 simulation results (red) for temporal variation of significant wave height, wave period, and wave direction (year 2017 and 2018)

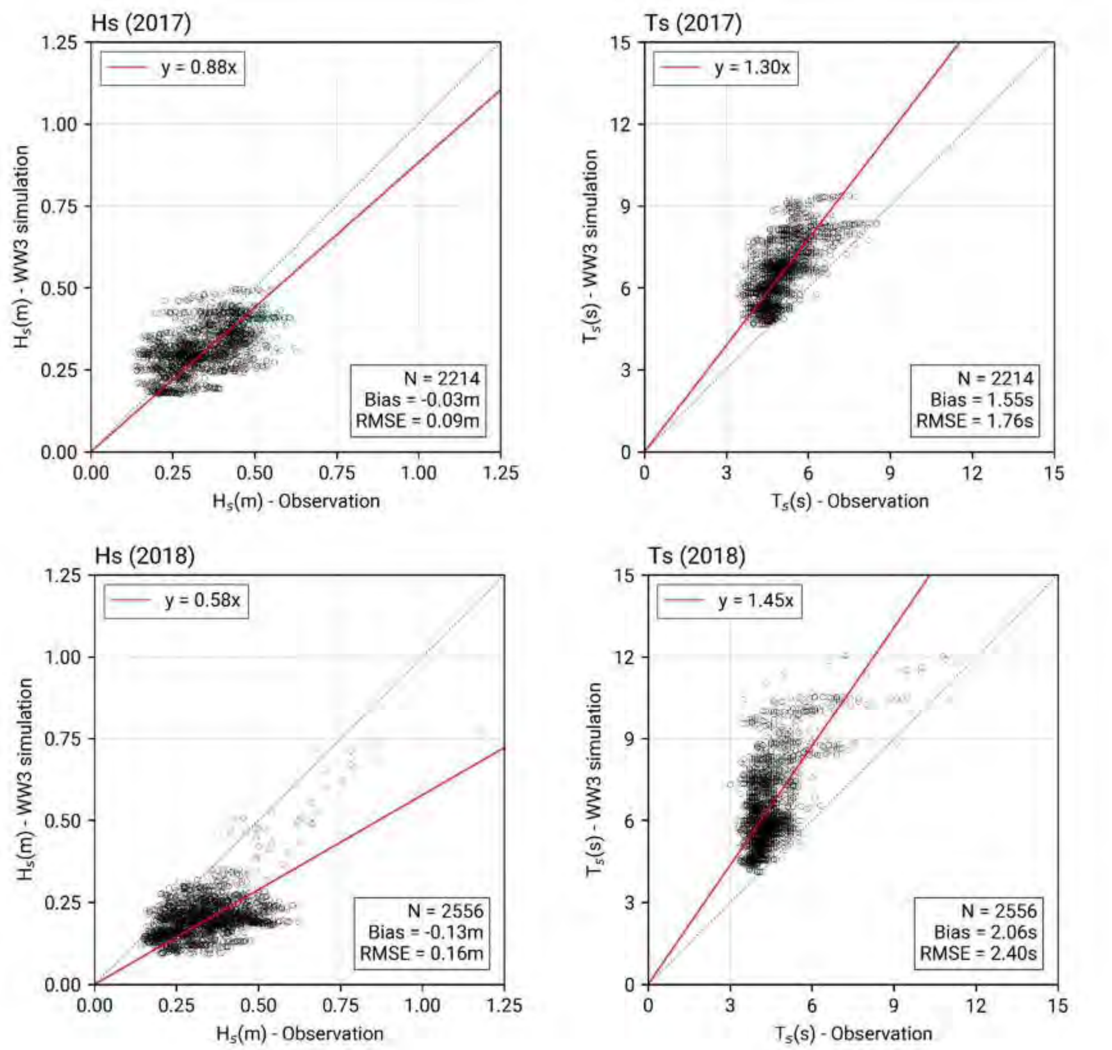


Figure 5-18 Comparison of significant wave height and wave period between observation and WW3 simulation (above: 2017 and below: 2018)

5.4.6 Extraction of wave estimation results

The time series data of offshore wave properties (significant wave height, wave period and wave direction) near Choiseul fishing port were extracted from 18-year (year 2000 to 2017) wave estimation results. Figure 5-19 below shows the extracted results for recent years 2016 and 2017, and results for other years are attached as Annex.

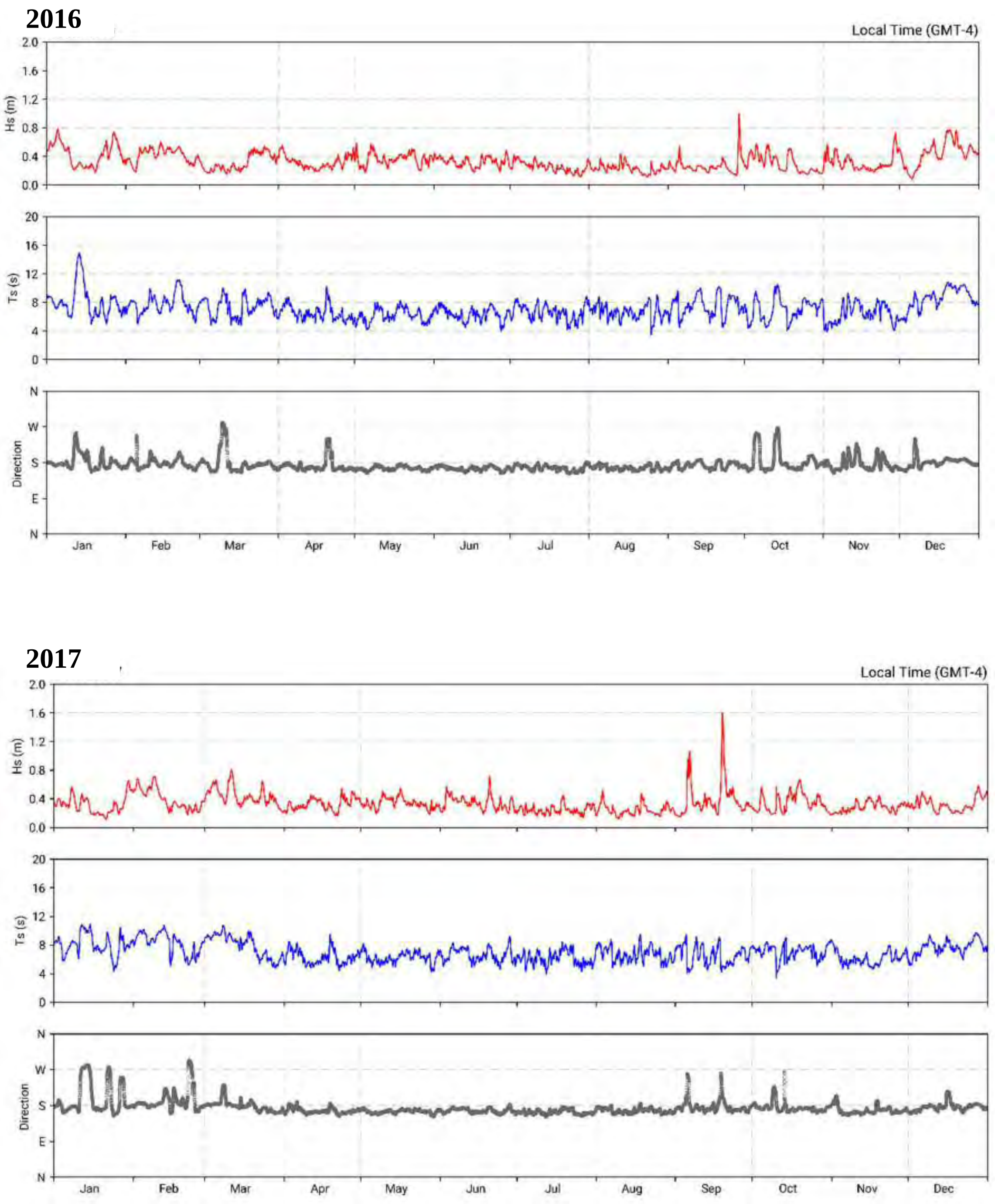


Figure 5-19 Wave height, period and direction for year 2016 and 2017

Chapter 6　Study on sand deposition factors

Chapter 6 Study on sand deposition factors

6.1 Condition before the construction of the Choiseul fishing port

In 1966, there was an approximately 100 m long pier in Choiseul as shown in Photo 6-1. Although, the pier was not a fishery related facility, it was used as a maritime transport base for people and luggage. It was broken when the hurricane struck and has not been rebuilt since that time. It seems that the demands for maritime transport have been diminished as land transportation system has been developed.

Referring to Photo 6-2, it is clear that the pier was a permeable structure supported by piles. This is one of the structural types that has the least impact on the surrounding terrain.

Photo 6-1 The pier in Choiseul in April 18, 1966

Photo 6-2 The pier in Choiseul (Unknown date)

Figure 6-1 shows topographic maps drawn from aerial photographs respectively taken in 1977 and 1992. Comparing these maps, there are two big differences. One is that the pier existed in 1977 but disappeared in 1992, and another is the configuration of coastline.

To show the differences, the coastlines in 1992 and 1977 are superimposed on Figure 6-2. The area colored in red is the difference between the two coastlines. In other words, a part of sea area in 1977 became land in 1992. Sedimentation was caused at concave depressions in coastline, and no deposited points can be found in southern and northern coast. A characteristic of the deposited topography is its north end being hook-like topography. It is still unclear from this figure whether the deposition has gradually progressed between 1977 and 1992, or has occurred rapidly in a relatively short period.

Figure 6-1 Comparison of topographic maps in 1977 and 1992

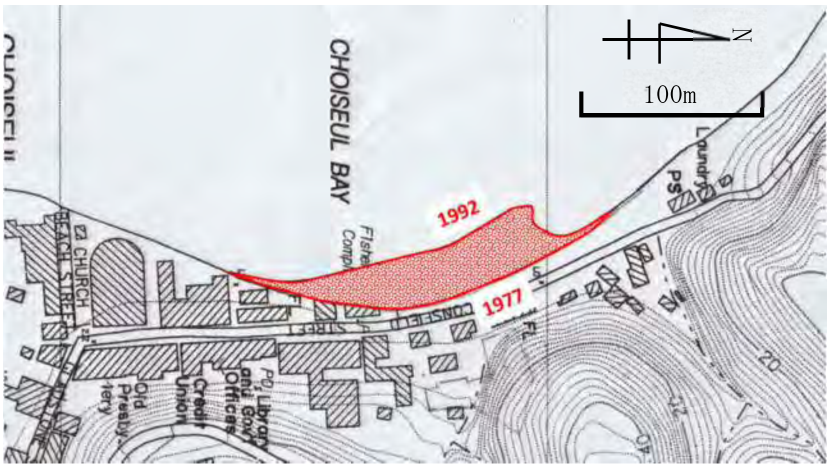


Figure 6-2 Superimposed coastlines in 1977 and 1992

Figure 6-3 shows the coastlines of 1977 and 1992 superimposed in blue and red, respectively, based on the bathymetric survey data obtained in July 2000. The ±0 m contour line in 2000 colored in green and the coastline of 1992 are closely overlapped, and the hook-like topography at the northern end of the depositional landform is also found in both coastlines. Therefore, topography of the deposited area was stable without changing for about eight years from 1992 to 2000. Since it was stable for a long time, it is considered that the deposition occurred during a period from 1977 to 1992 was rapid caused by any abnormal phenomena.

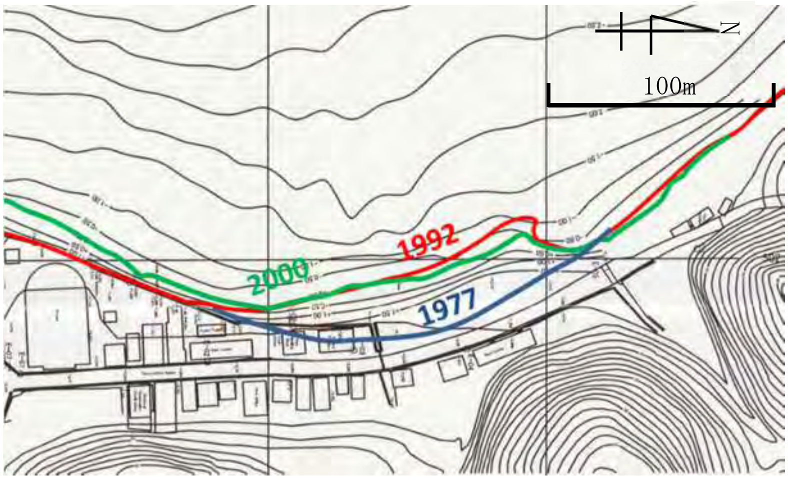


Figure 6-3 Superimposed bathymetric map in July 2000, coastlines in 1977 and 1992

Photo 6-3 shows the coast before the construction of the Choiseul fishing port. It was taken in the same month as the bathymetric survey conducted in July 2000. The deposited topography near the center of the coast and the characteristic hook-like topography can be confirmed as shown by a yellow arrow in Photo 6-3. On the north coast (front coast in the Photo), it seems that the swash zone is composed of gravel, and the beach where boats are pulled up is composed of sand.

Photo 6-3 Coast in July 24, 2000, before the construction of the Choiseul fishing port

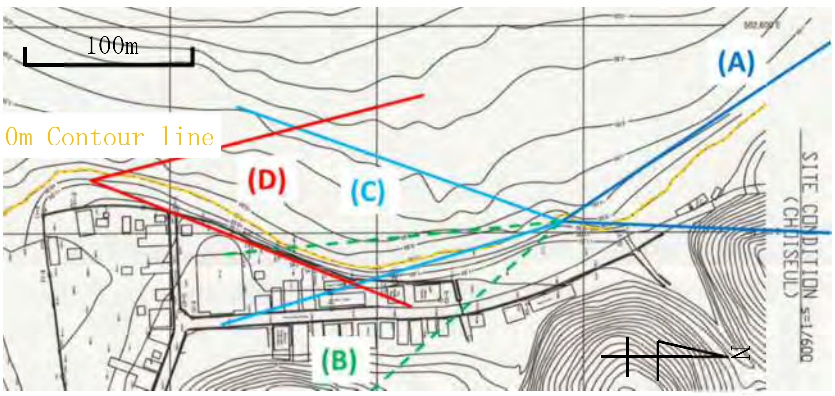


Figure 6-4 Locations and directions of photography

Figure 6-4 shows the locations and directions for Photos 6-4 to 6-6 shown below.

In the foreground of Photo 6-4, which is taken in the direction of (A), the hook-like topography can be seen and clearly cobble stones are deposited. The cobbles on the swash zone are covered with green seaweed, so it is assumed that this photo was taken at the time of low tides and these cobbles would not be transported by usual waves.

Direction (A)

Photo 6-4 The north coast taken from the vicinity of the hook-like topography in July 23, 2000

Direction (B)

Direction (C)

Photo 6-5 The south coast seen from around the hook-like topography in July 23, 2000

Photo 6-5 shows the conditions of the south coast seen from the location of the hook-like topography. Currently, the Choiseul fishing port has been constructed at this location. Many cobble stones are deposited at above the water surface. According to the picture in the shooting direction (C), it seems that seawater is turbid and sand is transported in suspension. In addition, the stones scattered underwater are large in size.

Photo 6-6 was taken in the Direction (D) seen from the right side of river mouth of the Choiseul River. The coast is mostly covered with gravel and cobble stones.

Photo 6-6 Direction (D) taken from the vicinity of the Choiseul River in July 23, 2000

Summarizing the above, conditions of the sand transport before the construction of the Choiseul fishing port is as follows.

At a certain time during the period between 1977 and 1992, a sudden and large-scale natural anomalous phenomenon occurred, and large amount of deposition occurred in the place where the Choiseul fishing port was constructed later. The depositional landform is characterized by its north end being hook-like topography, and it is inferred that its depositional materials were transported from the south and the area around the hook-shaped was the limit to which cobble stones can be transported.

Then, the depositional landform had not changed substantially and the hook-like topography remained for about 8 years until July 2000. It is considered that phenomena exceeding the abnormal phenomenon from 1977 to 1992 did not occur during this period.

According to Photo 6-3 to 6-6 taken in July 2000, cobble stones are deposited in the swash zone of area from the near mouth of the Choiseul River to the hook-like topography. Because seaweed adheres to surface of the cobble stones near the sea surface, cobble stones are usually not rolled or transported. It seems that gravels are deposited on the northern coast of the hook-like topography and cobble stones are not deposited there.

In the photographs taken in 2000 (e.g., Photo 6-5 shooting direction (C)), deposit of sand below the sea surface can be seen. Although the sea looks calm, the sea water near the shoreline is turbid and sand is transported in the state of beach drift. In other words, sand was expected to be always transported along the coast, but since depositional landform was mainly composed of is cobble stones, the landform was stable for a long time.

6.2 Construction of Choiseul fishing port and deposition of cobble stones

6.2.1 The deposition of cobble stones that suddenly appeared in the Choiseul fishing port

The construction of the Choiseul fishing port began on January 31, 2002, and the substructure of the breakwater was completed in June, the main part of the breakwater was completed in August, and the wave dissipating blocks were installed in front of the breakwater in November 2002.

The deposition in the Choiseul fishing port was recognized on November 28, 2002. At about 7:30 a.m. on the same day, deposition of cobble stones above the surface of the sea was found just on the inner side of the port near the wave dissipating blocks at the tip of the breakwater. Deposition that did not exist the day before suddenly appeared.

Photo 6-7 and 6-8 were taken on November 28, 2002 when the deposition of cobble stones was recognized. It is inferred that Photo 6-7 was taken in the early morning because shadows are recognized under the trees in the distant view. The sea surface is very calm with no waves, and cobble stones are highly unlikely to be carried behind the breakwater under this sea condition. In that case, waves that carried the cobble stones to the inside of the port occurred between the day before when such deposition was not found and 7:30 a.m. on November 28, 2002.

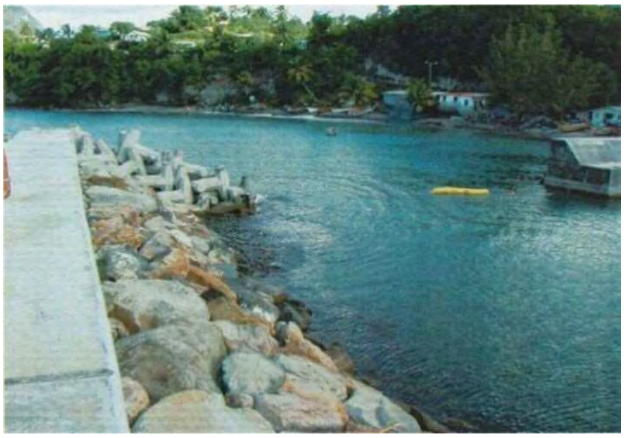


Photo 6-7 Deposition of cobble stones behind the breakwater in the morning, November 28, 2002

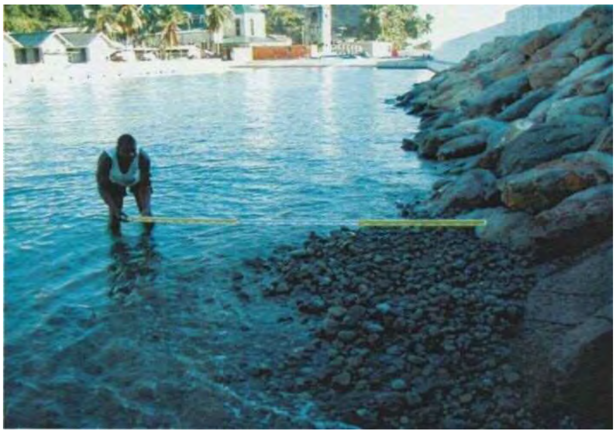


Photo 6-8 Deposition of cobble stones behind the breakwater on Sunday in November 28, 2002

Photo 6-8 is supposed to be taken late in the afternoon because the inside of the breakwater is shaded and the worker having a survey stuff is not illuminated by sunlight. Even in the fishing port in the photo, there is no waves that can carry cobble stones to the port. The top of the deposited cobble stones is found above the surface of the sea. Since the sea level is below the knees of the worker, it is understood that cobble stones deposited underwater as well. Now, it is hypothesized that there was a big wave that brought cobble stones into the fishing port early in the morning from November 27 to November 28. When the peak of the wave height energy has passed and become a decreasing phase, gradually stones are not carried in order of the particle sizes from the largest and sand with small particle size are suspended and carried for a long time. Then, composition of the deposition should be sand on cobble stones. However, only cobble stones are deposited above the sea surface and sand are not deposited. Photo 6-9 shows the deposition as of December 16, 2002, and sand deposition is not observed. Actually, as a result of consideration in 6.3, it is very likely that this cobble stones were pumice stones.

Photo 6-9 Deposition on December 16, 2002

The close-up photos of the deposition were taken after 2 months, on February 6, 2003, shown in Photo 6-10 and Photo 6-11. Photo 6-10 shows the overall situation of the deposition. Photo 6-11 is the close-up photo of the deposition, and the white stick in the center is a triangular scale for 15 cm (actual length: 16.8 cm). As of February 6, 2003, the deposition had a wide range of particle sizes from fine sand to stones with a diameter of about 15 cm or more.

Photo 6-10 Deposition in the port on February 6, 2003

Photo 6-11 Close-up photo of the deposition on February 6, 2003; white stick is a triangle scale with a real length of 16.8 cm

6.2.2 Movement of the deposition of cobble stones to the interior of the port

The available photos are arranged in chronological order to show the deposition of cobble stones moving to the inner side of the port.

Photo 6-12 to 6-17 were taken between December 30, 2002 and February 24, 2003. In order to easily follow the movement of the deposition of cobble stones, the same stones shown in each photo are marked with □, ▵ and ☆. Mark ▵ and north breakwater are connected by white dashed lines.

Photo 6-12 shows the condition on December 30, 2002. The deposition of cobble stones is located near the port entrance, outside of the dashed line, and the point marked □ is closely in the center of the deposition. Photo 6-13 shows the condition on January 6, 2003. Compared to photo 6-12 taken in 7 days ago, it seems that the deposition area on the water surface is extended. However, because the tide level in Photo 6-12 is high, it is judged that the amount and position of the deposition have not changed.

Photo 6-12 December 30, 2002

Photo 6-13 January 6 2003

Furthermore, on February 3, 2003, the deposition clearly moved to the interior of the port, rightward in Photo 6-14. The edge of the moved deposition almost reaches the midpoint between the mark △ and the mark ☆. In comparison with Photo 6-13, port entrance side of the deposition approached the mark □. It suggests that there was no (or just a little) supply of cobble stones from outside of the port in the process of the deposition of cobble stones being moved toward the interior of the port.

Photo 6-15, on February 6, 2003, was taken after 3 days from photo 6-14. Compared to Photo 6-14, the top of the deposition of cobble stones slightly developed over the mark ☆ to the interior of the port just in 3 days. It seems that developed area of the deposition is composed of sand, not cobble stones.

Photo 6-14 February 3, 2003

Photo 6-15 Deposition on February 6, 2003 (repost of photo 6-10)

The deposition that once developed beyond the mark ☆ to the interior of the port was eroded back to the mark ☆ and sand disappeared, and the surface of the tip was covered with cobble stones on February 17, 2003 as shown in Photo 6-16. A part of the disappeared sand seems to have been landed between the mark △ and the mark ☆, but the amount is small, thus possibly most of the sand has been transported to further interior of the port.

Photo 6-17 was taken on February 24, a week later from Photo 6-16. The tip of the deposition developed again beyond the mark ☆ and further to the interior of the port. The edge of the deposition is covered with cobble stones. However, although cobble stones are scattered under water surface, it seems the sand deposits on the gentle slope. Sand has been landed beyond the area between mark △ and mark ☆ in the central part of the deposition.

Photo 6-16 on February 17, 2003

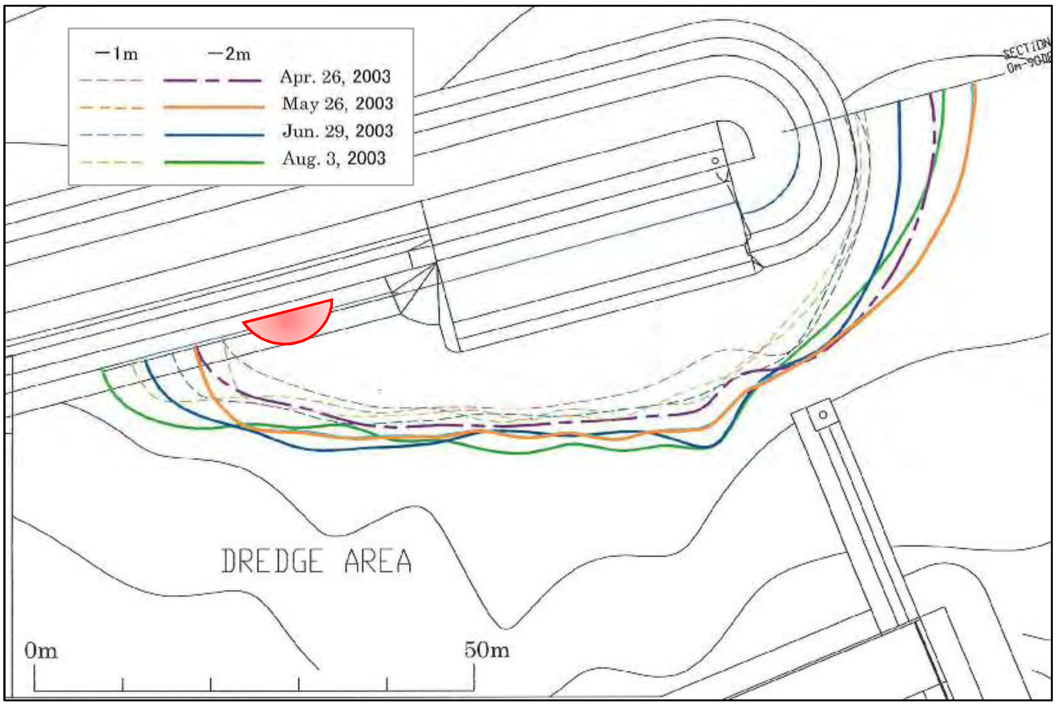
Photo 6-17 on February 24, 2003

As confirmed above, the deposition in the port mainly consisting of cobble stones moved to the interior of the port, and sand accumulation, disappearance and sand lift-up occurred at the tip.

6.2.3 Deposition after the dredging works of cobble stones

Figure 6-5 shows the topography in the port from April 26 to August 3, 2003, with contour line of -1 m and -2 m. Regarding the -2 m contour lines at the interior of the port, its position moved about 11 m along the breakwater towards interior of the port in 102 days from April 26 to August 26. The deposition has extended to the interior of the port at an average moving speed of approximately 0.11 m / day.

According to the records, cobble stones and other sands were dredged and removed, during a period from May 10 to May 24, prior to the completion ceremony of the construction of Choiseul fishing port on May 28, 2003. The dredged amount was about 700 m^3. The dredging work was completed on May 26. On a closer look at Figure 6-5, the -1 m contour line as of May 26 is also drawn. It is inferred that the dredging work was performed at the area with water depth shallower than -1 m, and foundation of the deposition deeper than -1 m remained.



* The area marked in red is the deposition on the sea surface that is recognized in the photograph taken on June 29 as shown in Photo 6-18

Figure 6-5 Depositional landform in the port observed from April 26 to August 3, 2003 [1)]

【Reference】

1) Report of the study for sedimentation mechanism and the maintenance method in Choiseul fishing port, ECOH CORPORATION, February 2005.

Photo 6-18 shows the deposition that appeared above the sea surface in the fishing port, which was photographed on June 29, 2003. The approximate location of deposition on the sea surface is shown in Figure 6-6 with a red hatch. The deposition was found further interior part of the port, not on the center of the foundation that was left. It is assumed that the sediments composing the foundation were carried further to the interior of the port by the waves intruding from the port entrance, and were deposited above the sea surface. Although it is difficult to specify the material from this photo, the material deposited above sea surface is probably sand. If so, the cobble stones were removed by dredging work and then new stones were not deposited after dredging work.

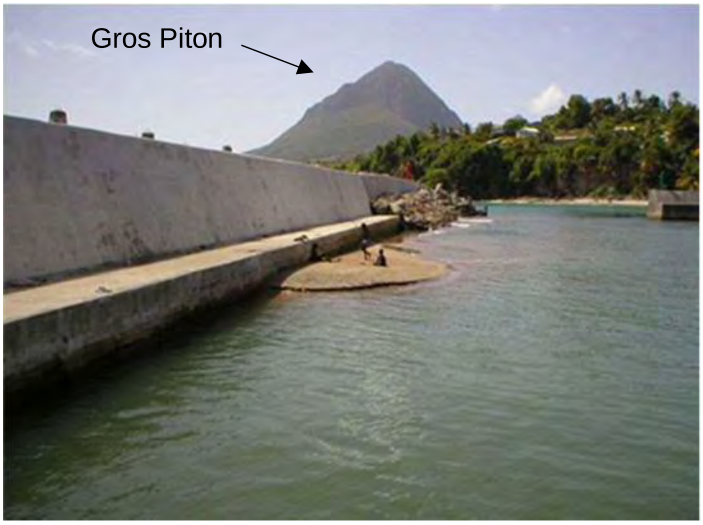


Photo 6-18 Deposition appearing on the sea surface in the fishing port taken on June 29, 2003

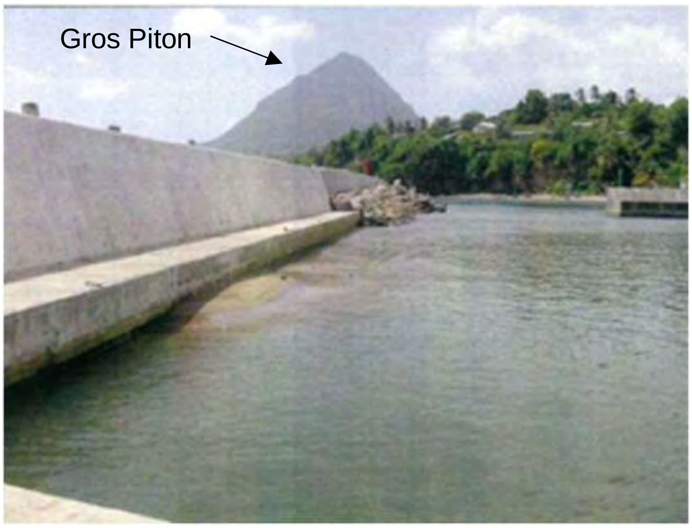


Photo 6-19 August 3, 2003

The deposition in Photo 6-19 looks like sand. In comparison of Photo 6-18 and Photo 6-19, it is easily understood that the deposition moved to interior of the port along the breakwater, referring to the relative positional relationship between the head of the wave-dissipating blocks above the breakwater and the mountain, Gros Piton.

Photo 6-20 September 16, 2004

Photo 6-21 Dredging work by backhoe on September 21, 2004

Photo 6-22 Dredging work by backhoe on October 19, 2004

Photo 6-20 shows the deposition in the port after one year from Photo 6-19. Deposition extended to the interior of the port, and it spread to a wider area in the port. Cobble stones are not recognized in this photo. Shortly after this, a dredging work by a backhoe began as shown in Photo 6-21 and 6-22. According to Photo 6-22, the deposited material is apparently sand and does not contain cobble stones.

Among the above things, following matters should be noted.

Prior to the construction completion ceremony of the Choiseul fishing port, the deposited area behind the breakwater was dredged at the area with the water depth shallower than -1 m. At this time, most of the cobble stones including those deposited above the sea surface were removed. The deposition below the sea surface extended to the interior of the port, and the deposition appearing above the sea surface moved to the interior of the port. However, no cobble stones deposited in the port after dredging work.

6.2.4 Current status of the distribution of cobble stones

The cobble stones have deposited in the port as they appear above the sea level for approximately six months from November 2002 to May 2003. After removing the cobble stones, no record of cobble stones being deposited in the port has confirmed for about 15 years until September 2018, as described in the following chapter.

Figure 6-6 Places where cobble stones are accumulated or scattered
(Google Earth, taken on March 24, 2018)

When the area around the fishing port was examined, cobble stones were accumulated or scattered at the points shown in Figure 6-6. The features of points (1) to (8) are as follows.

(1) River upstream

Photo 6-23 shows the river channel about 300 m upstream from the mouth of the Choiseul River. The bottom of the river is not the natural condition because dredging works by a bulldozer were conducted around here about 2 weeks before shooting, but there are cobble stones on the slope and the riverbed.

Photo 6-23 A point about 300 m from the mouth of the Choiseul River on December 6, 2017

(2) Base of sea cliff

At the base of the sea cliff, there are cobble stones that are thought to have fallen due to the erosion of the cliff.

(3) Sea bottom at river mouth

A photo 6-24 taken by a drone in November 2017 shows a black shadow linearly extending from seabed in front of the Choiseul river mouth to offshore. The bathymetric survey at the same time shows contour lines projecting to offshore directions from the river mouth (see Figure 6-7). There are cobble stones on the river as shown in Photo 6-23. From these facts, the black shadow in Photo 6-24 is considered to be the sediment that flowed out of the Choiseul River.

Through the underwater survey in the river mouth by divers in the second site work, it was confirmed that stones with various sizes from cobble stone size to 80 cm in diameter were accumulated as shown in photo 6-25. The dark shadow in the drone image was algae covering the stone surface.

Photo 6-24 A black shadow of the sea bottom extending to offshore in the front of the river mouth
(Taken by drone on November 25, 2017)

Figure 6-7 Depositional landform on the sea bottom in front of the Choiseul River mouth
(Survey on November 2017)

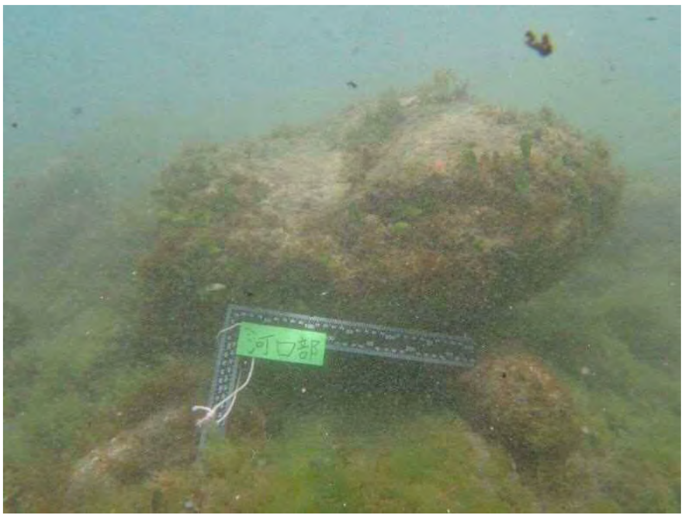


Photo 6-25 Condition at the bottom of the river mouth
(Photographed on August 8, 2018, scale length is 30 cm)

Photo 6-26 shows the diver measuring the accumulation area of cobble stones. The diver raised the GPS device above the sea surface and moved along the boundaries of the cobble stones. Also, the diver observed visually the condition of the seabed. Figure 6-9 shows the accumulation area of cobble stones comprehended by the survey.

Photo 6-26 Measuring of the accumulation area of cobble stones

Figure 6-8 Accumulation area of cobble stones on September 3, 2018

It is considered that the cobble stones deposited in front of the river mouth are not constantly provided from the river every year, but such cobble stones are discharged altogether at the time of very large and rare floods.

Photo 6-27 is a temporary road constructed at the mouth of the Choiseul river for the construction of the Choiseul fishing port. The temporary road completely blocks the Choiseul river mouth, so a pipe with a diameter of 600 mm is installed to discharge the river water. Since the diameter of pipe seems to be enough to drain the water from the river, it is inferred that sediment discharge including cobble stones from the Choiseul river is usually scarce. Sediment discharge occurs during a major flood. Considering the situation in Anse La Raye, the recent major flood from February 2009 was probably at the time of the hurricane Tomas attack on October 30, 2010. At that time, a large amount of sediment including cobble stones flowed out of the Choiseul river to the sea. Sand as well as cobble stones should have been included, but sand was unlikely to be deposited in front of the river mouth since the sand could be carried easier than cobble stones.

Photo 6-27 Temporary road and drainage pipe in the Choiseul river mouth

(4) Shoreline at river mouth

The cobble stones are also accumulated in the land area of the river mouth as seen in Photo 6-28. The cobble stones on the shoreline, indicated as "shoreline" in the photo, where the waves are affecting almost continuously are dark-colored.

Photo 6-28 Cobble stones at river mouth on August 18, 2018

(5) Backshore at river mouth

Cobble stones are also deposited on the backshore of the land area in the river mouth, shown as "land" in Photo 6-28. Looking at the close-up photo of the backshore in Photo 6-29, it is recognized that the deposited cobble stones are whitish and sand is deposited among the cobble stones.


Photo 6-29 Close-up photo at backshore on August 18, 2018

(6) Seabed at port entrance

Photo 6-30 is the entrance of the Choiseul fishing port taken by a drone. A black shadow, enclosed by dashed line in Photo 6-30, is observed on the seabed just outside of the port entrance. Actually, at the site, deposited cobble stones were confirmed as seen in Photo 6-31. The surface of stones covered by moss-like material. This means that these cobble stones do not roll on the seabed and stay the same place stably. Figure 6-9 shows the results of measuring the distribution area of cobble stones by walking along the boundary of accumulation area of the cobble stones and the sand with GPS. It roughly matches the area of the black shadow recognized in Photo 6-30.

Photo 6-30 Black shadows of the seabed at the port entrance on November 25, 2017

Photo 6-31 Cobble stones accumulated in the port entrance on November 29, 2017; the long side of the red Level book is 16.5 cm

Photo 6-32 Measuring of accumulation area of cobble stones on November 29, 2017

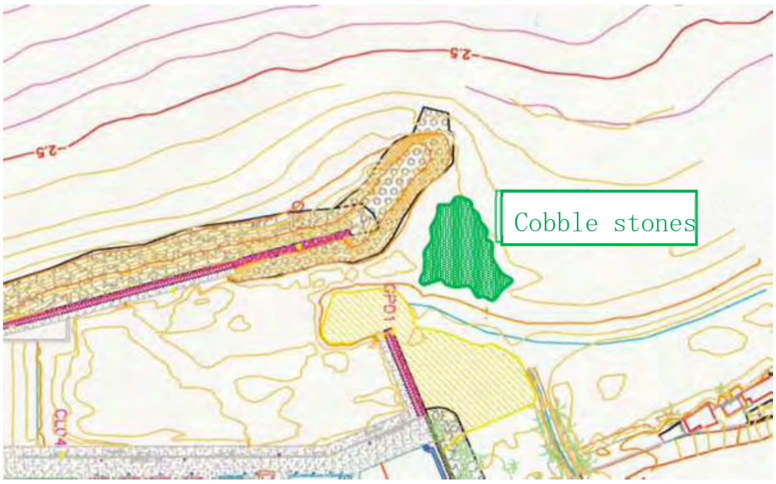


Figure 6-9 Accumulated area of cobble stones on November 29, 2017

The same diver measured accumulated area of cobble stones on August 19, 2018, approximately 9 months later from first site works, Figure 6-10. The accumulations of cobble stones were confirmed at two places. Probably, the change of accumulation areas of cobble stones is not caused by waves, but by some effects of dredging work by a backhoe which is a yellow machine stayed at the lower side in Figure 6-10. For instance, sand deposited on cobble stones, and/or sand covering the cobble stones was removed.

Figure 6-10 The cobble stone accumulation area in the port entrance on August 13, 2018

Figure 6-11 shows the 1992 coastline superimposed on the cobble stone accumulation area on November 29, 2017 as shown in Figure 6-9. The longshore location of cobble stones is closely agreed with that of the hook-like part of the depositional landforms confirmed in 1992. As pointed out in the previous section, the location of the hook-like topography is the limit point where waves can transport the cobble stones along the coast. The cobble stones are possibly carried and go around the tip of the additional breakwater in case of abnormal weather conditions. Once cobble stones are moved to the back side of the additional breakwater, cobble stones are stabilized because the area is protected by the additional breakwater decreasing the coming wave heights.

It is presumed that the formation of hook-like topography, which is recognized in the topographic map in 1992, was caused by the infrequent abnormal weather conditions. Therefore, deposition of cobble stones is thought to be occasional, and resultantly it is not taken into consideration for countermeasures in this study.

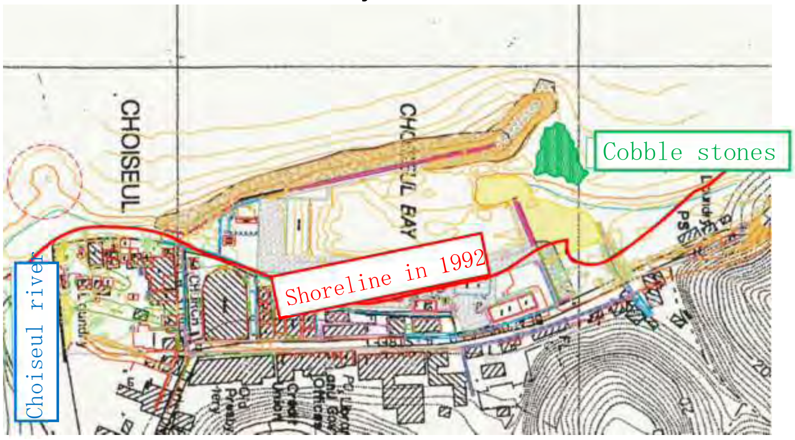


Figure 6-11 Positional relation between the accumulation area of cobble stones and the coastline in 1992 (Yellow contour line surveyed in November 2017)

(7) Land area of port entrance

Photo 6-33 shows the conditions at the land area of port entrance. The cobble stones are not accumulated but scattered on the foreshore.

(8) North beach

Cobble stones are scattered on the backshore in the north beach, but sizes of the most cobble stones are small as seen in Photo 6-34.

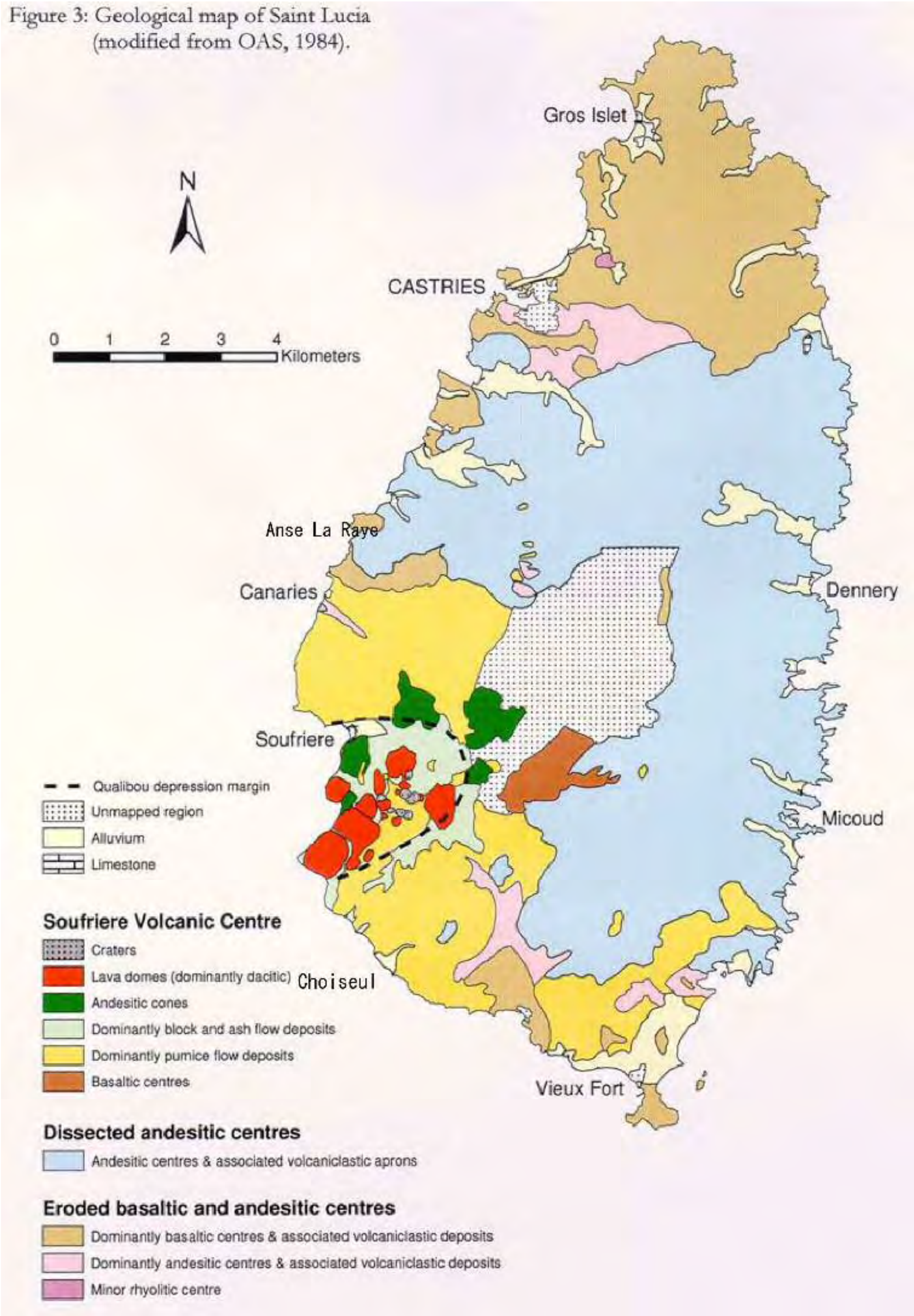
Photo 6-33 Cobble stones scattered in land area of port entrance on August 10, 2018

Photo 6-34 Cobble stones collected in north beach on August 10, 2018

6.3 Specific gravity for cobble stones

6.3.1 Geological map of Saint Lucia

Figure 6-12 shows the geological map of Saint Lucia. According to this figure, the geology of the area around the Choiseul fishing port is mainly composed of "pumice flow sediments". In order to confirm this, the specific gravity of the cobble stones around the fishing port has been examined.



Reference：University of the West Indies　URL：http://uwiseismic.com/G eneral.aspx?id=72
Latest viewing date：November 5, 2018

Figure 6-12 Geological map of Saint Lucia

6.3.2 Collection of cobble stones and measurement for specific gravity

The cobble stones have been collected from eight places as shown in Figure 6-6, where cobble stones are accumulated or scattered. Table 6-1 shows the number of collected cobble stones from each point, sizes and the collection date. For instance, photo 6-35 and 6-36 show collected samples from (5) Backshore at river mouth and (6) Seabed at port entrance, respectively.

Table 6-1 Data about collected cobble stones

Regional classification	Collected point (Refer to Fig 6-6)	Collected number	Size (Equivalent diameter)	Date (2018)
Sand supply source	(1) River upstream	28	10～14cm	August 10
	(2) Base of sea cliff	3	11～12cm	August 10
River mouth	(3) Sea bottom at river mouth	28	9～14cm	August 9
	(4) Shoreline at river mouth	28	10～14cm	August 30
	(5) Backshore at river mouth	31	8～13cm	August 16
Port entrance	(6) Seabed at port entrance	28	8～11cm	August 26
	(7) Land area of port mouth	45	5～12cm	August 10
North beach	(8) North beach	28	3～10cm	August 10

Photo 6-35 Cobble stones collected in (5) Land area at river mouth; the long side length of the field book is 16.5 cm

Photo 6-36 Cobble stones collected in (6) Seabed at port entrance the long side length of the field book is 16.5 cm

The collected cobble stones can be divided into the following three by the observation of the surface with naked eyes.

a. A cobble stone with white substrate and mineral can be identified (Photo 6-37a)

b. A cobble stone with reddish substrate and minerals can be identified (Photo 6-37b)

c. A porous cobble stone with white substrate and slight minerals (Photo 6-37c)

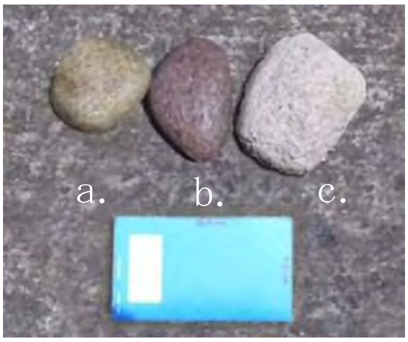


Photo 6-37 Appearance features of cobble stones in 3 types
(long side of field book is 16.5 cm)

On the surface of cobble stones a. and cobble stones b., minerals such as hornblende, featured by black and rectangle, and plagioclase, featured by gray white and irregularly shaped can be visually confirmed, and the volcanic zone consists of andesite located in the vicinity (see Figure 6-12). Based on these conditions, these cobble stones are judged as andesite. The specific gravity of andesite generally varies from 2.5 to 2.8 as listed in Table 6-2.

Table 6-2 General Specific Gravity of Typical Rocks

Material	Specific Gravity
Andesite	2.5 - 2.8
Basalt	2.8 – 3.0
Granite	2.6 – 2.7
Limestone	2.3 – 2.7
Sandstone	2.2 – 2.8
Pumice	1.06

Reference：http://www.edumine.com/xtoolkit/tables/sgtables.htm Latest viewing date：November 11, 2018
https://www.iiste.org/Journals/index.php/CER/article/viewFile/3540/3588 Latest viewing date：December 10, 2018

The weights of the cobble stones have been measured on site. The maximum weight of digital scale is 50 kg, and the sensitivity is 0.01 kg. The weights in the air and in seawater have been measured as shown in Photo 6-38 and Photo 6-39. The specific gravity of seawater is assumed to be 1.02, and the specific gravity of stone is calculated by equation (1). Regarding the sample of small size, several samples are put together and the total weight is measured as one sample.

$$\text{Specific gravity} = \frac{\text{Weight in air}}{\text{Weight of water is equal to the volume of the stone}}$$

$$= \frac{\text{Weight in air} \times \text{Specific gravity of sea water}}{(\text{Weight in air} - \text{Weight in sea water})} \qquad (1)$$

Photo 6-38 Measuring of weight in air

Photo 6-39 Measuring of weight in seawater

6.3.3 Characteristic for specific gravity of cobble stones

Figure 6-13 is the specific gravity of all cobble stone samples. The vertical axis is the diameter calculated from the volume of the cobble stones considering them as spheres, and the horizontal axis is the specific gravity. Cobble stone samples can be divided into two groups in accordance with the specific gravity: 1.20 to 2.10 is Group A, 2.20 to 2.70 is Group B. Cobble stone c. shown in Photo 6-37 belongs to Group A, and the cobble stone a. and b. belong to Group B.

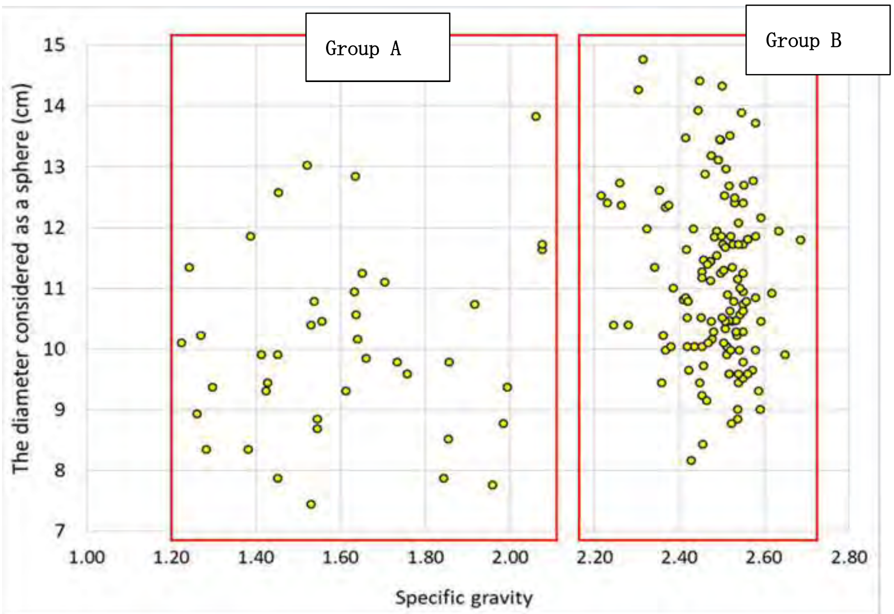


Figure 6-13 Specific gravity of cobble stones (all data)

Table 6-3 lists characteristics of specific gravity (average, maximum, minimum, standard deviation) by each collection point. The “collection number” in the table is the actual number of the collected stones. The “number of samples” is the number of small cobbles as one sample in case of weight measuring.

The average specific gravity of cobbles is low in (5) Backshore at river mouth and (8) Backshore at north beach, and does not tend to be gathered at specific places in each collection point as shown in Figure 6-14. Since these places are higher than the sea level, the wave runup seems to be related to landed cobble stones. On the other hand, standard deviations have regional characteristics. The standard deviations of sampling points (1) to (4) are small, and large in (5) to (8). Figure 6-15 shows standard deviations plotted on a plan view, standard deviations are smaller on near the source of sediment supply (left side in the figure) and larger on the lee side of sand transport (right side in the figure).

Table 6-3 List for specific gravity

Regional classification	Collected point (see Fig.6-17)	Sample number ／ Collected number	Specific gravity			
			Average value	Maximum value	Minimum value	Standard deviation
Sand supply source	(1) River upstream	28／28	2.45	2.69	2.26	0.09
	(2) Base of sea cliff	3／3	2.33	2.42	2.23	0.09
River mouth	(3) Sea bottom	28／28	2.49	2.65	2.28	0.08
	(4) Shoreline	28／28	2.46	2.63	2.06	0.12
	(5) Backshore	28／31	1.52	1.99	1.22	0.23
Port entrance	(6) Seabed	28／28	2.36	2.59	1.07	0.24
	(7) Land area	22／45	2.41	2.58	1.54	0.32
North beach	(8) Backshore	6／28	1.81	2.08	1.45	0.25

Figure 6-14 Average value of specific gravity of cobble stones

Figure 6-15 Standard deviations of specific gravity of cobble stones

Figure 6-16 shows the weights of cobble stones collected at (1) River upstream and (2) Base of sea cliff. These areas are possibly sand supply sources of sediments deposited in the Choiseul fishing port. The specific gravity of the two points are almost the same, and the specific gravity of all cobble stones are distributed within the range of Group B (2.20 to 2.70).

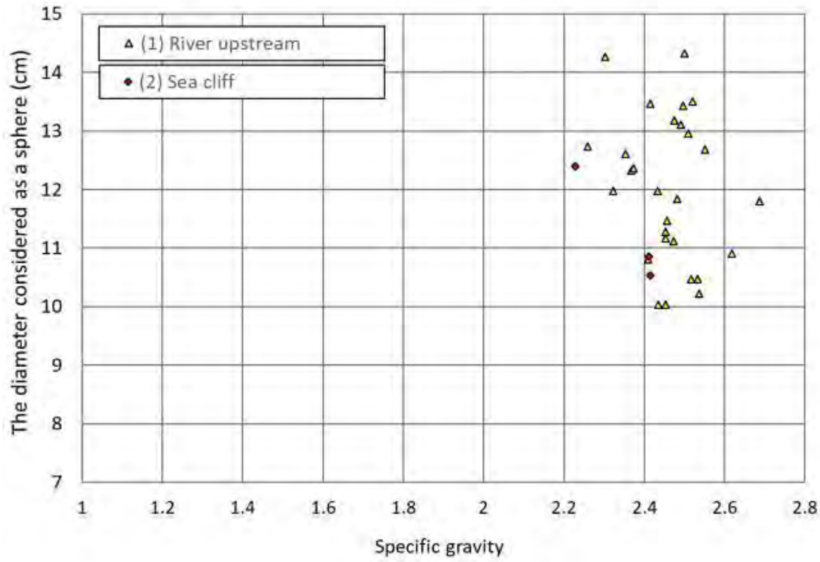


Figure 6-16 Specific gravity for (1) River upstream and (2) base of sea cliff

Figure 6-17 shows the specific gravity of cobble stones collected at three points in the river mouth ((3) Sea bottom, (4) Shoreline, (5) Backshore). In this figure, the specific gravity of the cobble stones at (1) River upstream is also plotted. According to this figure, all cobble stones in (1) River upstream, (3) Sea bottom at river mouth, and (4) Shoreline at river mouth are all included in Group B with high specific gravity, and cobble stones in (5) Backshore at river mouth are included in the Group A of low specific gravity.

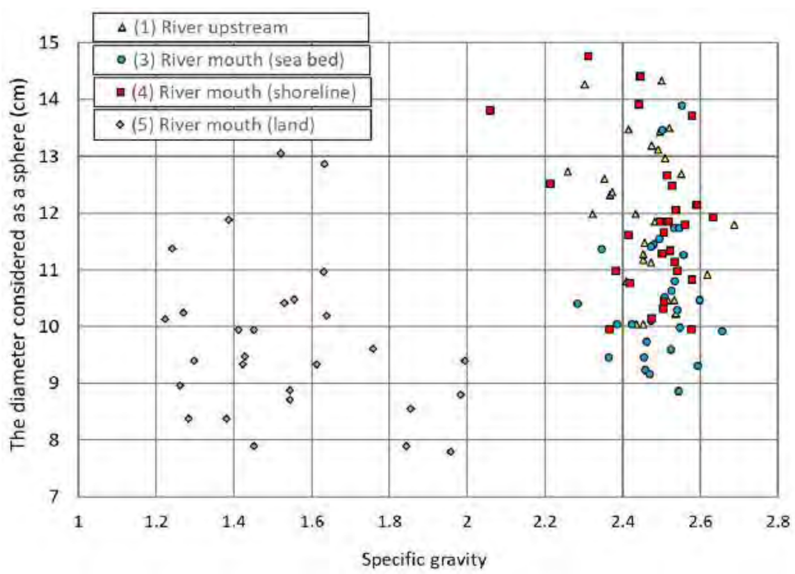


Figure 6-17 Specific gravity of cobble stones in the river mouth (Specific gravity of cobbles in (1) River upstream is also plotted)

Table 6-4 lists the ratio of cobble stones classified into three groups by appearance characteristics, and the number of cobble stones with algae on the surface. The ratio of cobble stone a. and b. collected in (1) River upstream, (3) Sea bottom at river mouth, and (4) Shoreline at river mouth is almost 1:1, and cobble stone c. (porous) is not included. On the other hand, all cobble stones in (5) Backshore at river mouth are classified as cobble stone c. Algae adheres to the surface of the cobble stones collected at (1) River upstream and (3) Sea bottom at river mouth. The types of algae are possibly different between freshwater and seawater, however, the adhesion of algae suggests that such cobble stones are in a stable condition, paradoxically referring to “a rolling stone gathers no moss”.

Table 6-4 Appearance characteristics ratio of cobble stones and number of algae adhesion

	Appearance characteristics（See Photo 6-36） Number(%)			Number of algae adhesion (%)
	Cobble stone a.	Cobble stone b.	Cobble stone c.	
(1) River upstream	12(43%)	16(57%)	0(0%)	10(36%)
(3) Sea bottom at river mouth	16(57%)	12(43%)	0(0%)	21(75%)
(4) Shoreline at river mouth	12(43%)	16(57%)	0(0%)	0(0%)
(5) Backshore at river mouth	0(0%)	0(0%)	28(100%)	0(0%)

From Figure 6-17 and Table 6-4, following can be guessed.

- Places of (1) River upstream, (3) Sea bottom at river mouth and (4) Shoreline at river mouth are in a physical condition where cobble stones with low specific gravity cannot be stable.
- Place of (5) Backshore at river mouth is in a physical condition where cobble stones with high specific gravity cannot be deposited.

The explanations of the physical conditions are slightly different between the former and the latter above because of the following reasons. With regard to the former, it is intended that, at the time of flood or stormy weather that carry and deposit cobble stones of high specific gravity, the cobble stones of low specific gravity which are carried simultaneously cannot stay because these are easily carried. In the latter case, since the ordinary waves do not run up to the backshore, it is considered that the backshore sediments have been carried by the wave runups during heavy weather. In heavy weather, cobble stones of low specific gravity and low weight sand are landed to the backshore, whereas cobble stones of high specific gravity are not landed up to the backshore even in this situation. Then, when waves get back to the ordinary conditions, the waves do not run up to the backshore, so the sediments that have been landed during stormy weather remain there. This explanation is consistent with the fact that sand is deposited on the backshore together with a cobble stones of small specific gravity (see Photo 6-28).

Figure 6-18 shows the specific gravity of cobble stones at the Choiseul fishing port entrance ((6) Seabed, (7) Land area). Both cobble stones of high and low specific gravity are found. However, most of the specific gravity of cobble stones (about 90%) is around 2.5, and the ratio of light cobble stones with the specific gravity of approximately 1.7 is low (about 10%). The mixing ratio of high and low specific gravity cobble stones is the same in (6) Seabed and (7) Land area. There are no differences between the two in terms of specific gravity. However, the percentage of cobble stones with algae adhesion to the surface (shown in Table 6-5) is 96% in (6) Seabed and 0% in (7) Land area. The difference between the two is clear. The cobble stones in (6) Seabed can be judged to be stable for a long period since its algae adhesion rate is extremely high like cobble stones in (3) Sea bottom. On the other hand, due to the constant dredging works by a backhoe near (7) Land area at port, the cobble stones are forcibly rolled around, also cobble stones are buried or excavated in and from sand. It is reasonable to assume that algae cannot adhere to such cobble stones.

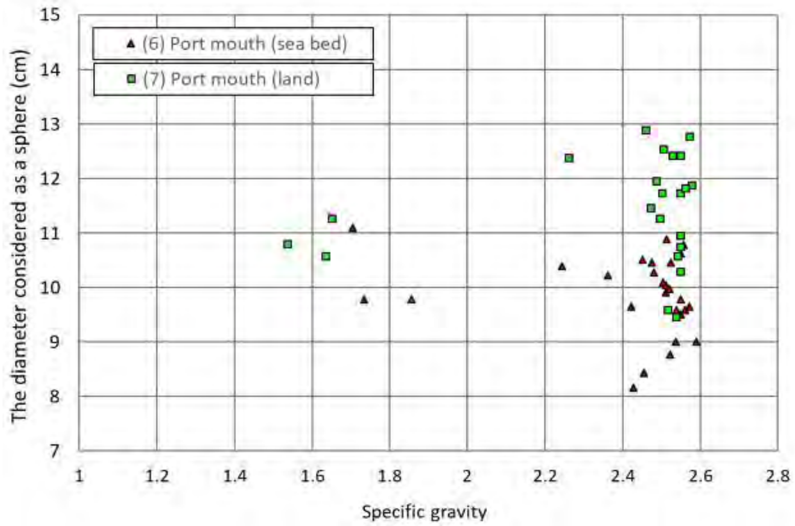


Figure 6-18 Specific gravity of cobble stones at port entrance of Choiseul fishing port

Table 6-5 Appearance characteristics ratio of cobble stones and number of algae adhesion at port entrance

	Collected number	Appearance characteristics (See Photo 6-36) Number(%)			Number of algae adhesion (%)
		Cobble stone a.	Cobble stone b.	Cobble stone c.	
(6) Seabed at port entrance	28	25(89%)	0(0%)	3(11%)	27(96%)
(7) Land area of port entrance	45	28(62%)	14(31%)	3(7%)	0(0%)

Figure 6-19 shows the specific gravity of the cobble stones landed on the backshore of the north beach. Specific gravity of cobble stones in (5) Backshore at river mouth is included again for comparison. According to this figure, specific gravity in (8) North beach is around 1.8. It is almost the same as the one in (5) Backshore at river mouth. Light stones are landed also. In addition, although the size of stones collected at the north beach are small, the diameter is about 10 cm in Figure 6-15. This is because the diameter was calculated by measuring several small stones collectively.

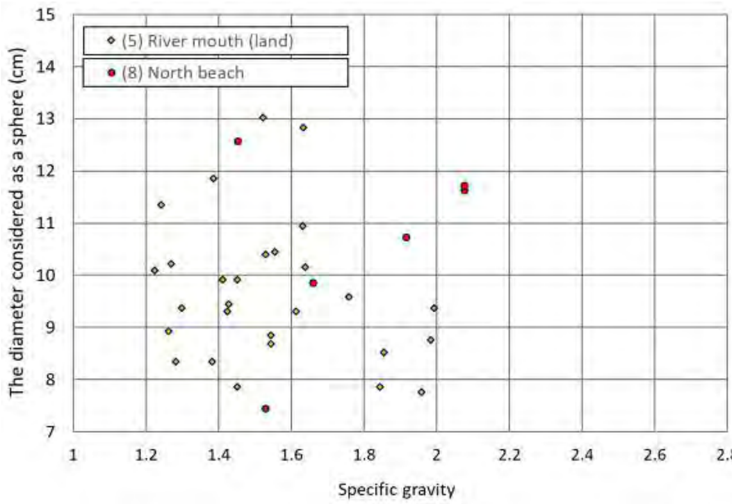


Figure 6-19 Specific gravity in (8) Backshore at north beach and (5) Backshore at river mouth

Summarizing the above quite simply, cobble stones with low specific gravity exist around the Choiseul fishing port as expected from the geological map. Such cobble stones are not found in the sea area where the river flow or sea waves act, but its distribution is limited only to backshore where usually waves do not act.

6.3.4 A study on the deposition of cobble stones that appeared suddenly

According to the survey mentioned in the previous section, it is confirmed that pumice exists around the Choiseul fishing port. Now, the deposition of cobble stones that suddenly appeared in the Choiseul fishing port on November 28, 2002 is considered. Specifically, considerations are corresponding to characteristics of the deposition summarized in 6.2. However, the deposited cobble stones at that time have been removed by dredging works prior to the completion ceremony, therefore the followings are inferences without enough evidence.

Feature 1: On the morning of November 28, 2002, cobble stones were deposited up to the elevation above the sea level.

Figure 6-20 shows the daily rainfall before and after the day when the deposition of cobble stones was observed (observation point: Hewanorra International Airport) and the waves of hindcasted value at the offshore of the Choiseul fishing port. Although the significant wave height at the offshore of the Choiseul fishing port exceeds 1 m at the time of the hurricane Lili on September 23, 2002, wave heights were less than 40 and some centimeter in two months from October to November before the appearance of the deposition. It means, under such calm sea conditions, cobble stones with its diameter about 15 cm or more were transported into the port. Looking at the photos of the day of discovery as shown in Photo 6-7 and Photo 6-8, deposited material is cobble stones and sand is not recognized. In other words, the smaller diameter sand is not carried into the port but the larger diameter cobble stones are carried. The physical explanation can be provided if the specific gravity of the cobble stones is low. Furthermore, the waves in the fishing port protected by the breakwater are very small. Under these conditions, the appearance of the deposition of cobble stones above the sea surface means that the specific gravity of such cobble stones is lower than the light cobble stones which currently exist around the Choiseul fishing port (about 1.20 to 2.10; see Figure 6-13). The geology of the area of the Choiseul fishing port consists of pumice flow deposits as shown in Figure 6-12. Also, according to the typical specific gravity of typical rocks listed in Table 6-2, the specific gravity of pumice is 1.06. Therefore, the existence of pumice lighter than the specific gravity 1.20 cannot be denied.

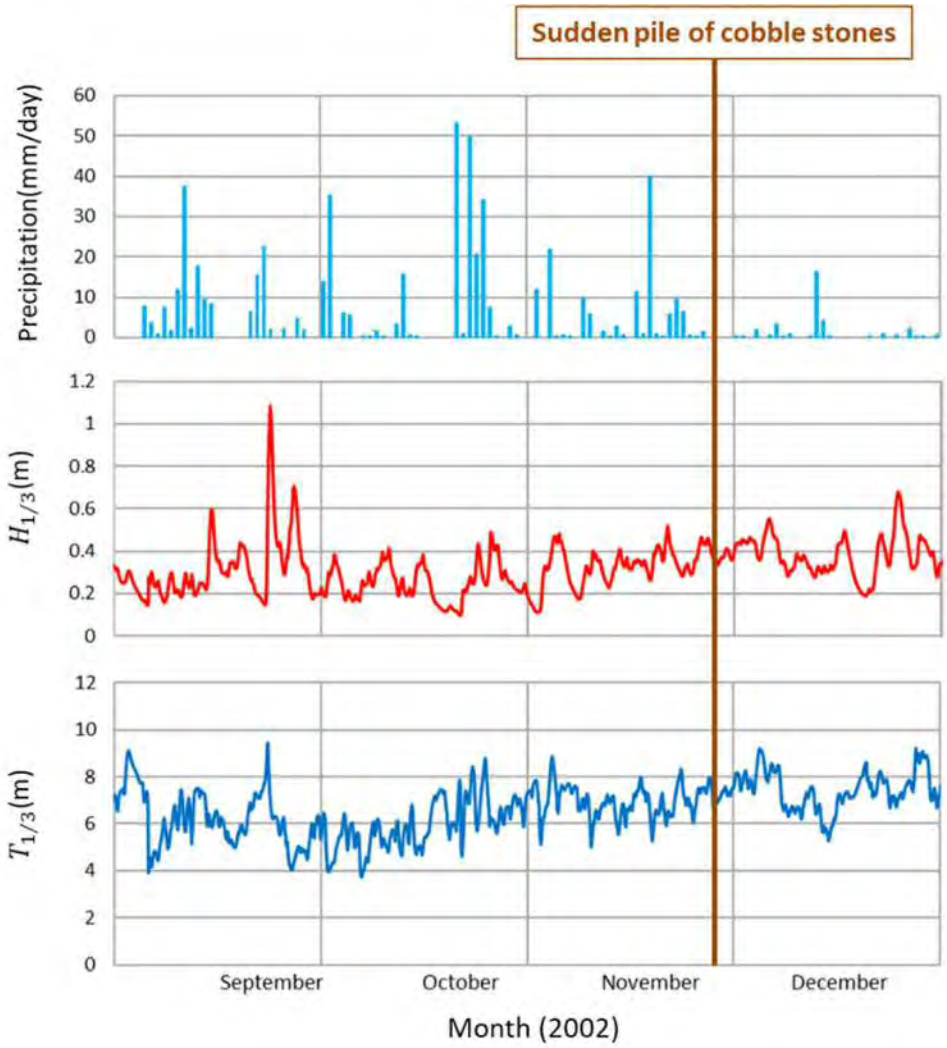


Figure 6-20 Rainfall (observed value) and waves (hindcasted value) before confirming sudden deposition of cobble stones

Feature 2: The deposition of cobble stones gradually moved toward the interior of the port.

The topography that appeared on the sea surface with cobble stones behind the breakwater in the port gradually moved to the interior of the port during a period from January 2002 and February 2003 (6.2.2). According to Figure 6-21, the significant wave height at outside the port during this period seldom exceeded 60 cm. The wave height inside the port was smaller. The movement of the cobble stones to the interior of the port by such small waves suggests that the specific gravity of cobble stones was rather low.

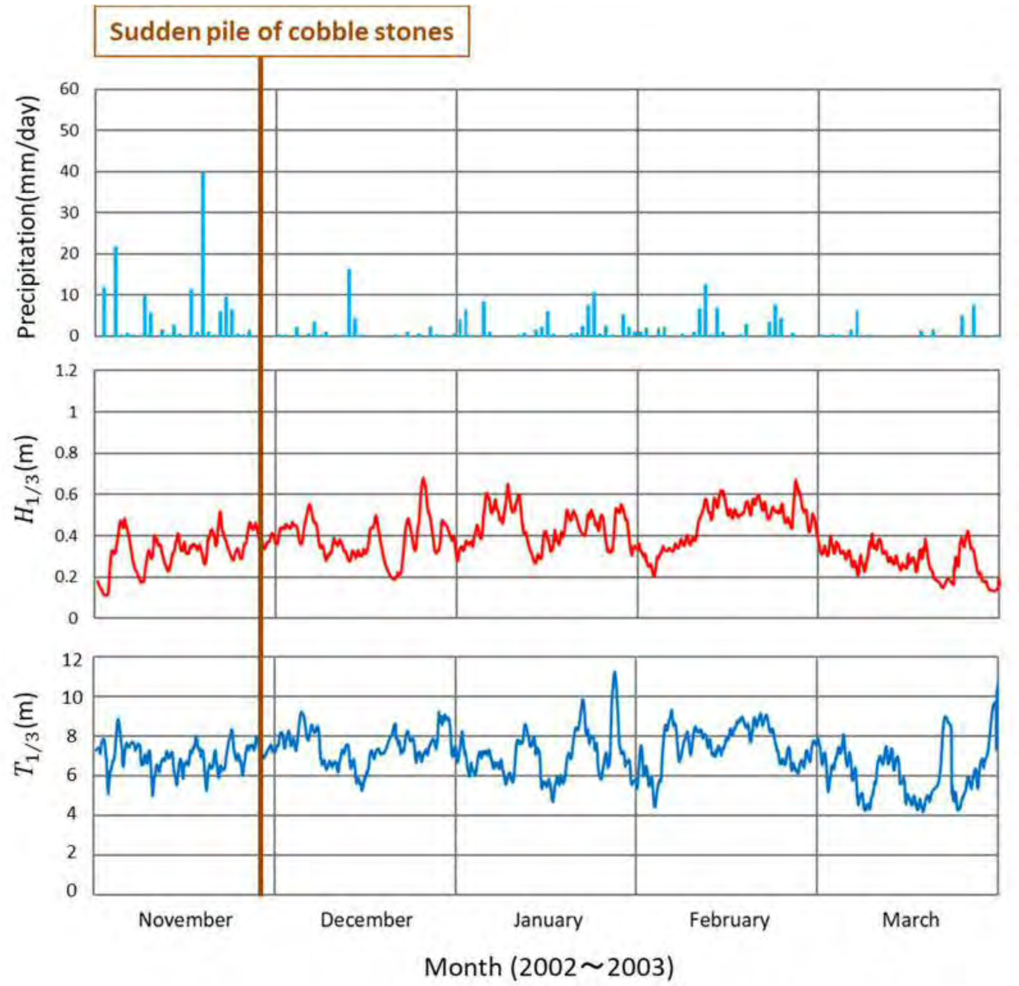


Figure 6-21 Rainfall (observed value) and wave (hindcasted value) after confirming the sudden deposition of cobble stones

Feature 3: After the dredging work, cobble stones have not appeared on the sea surface in the fishing port up to August 2018.

There have been no reports of the deposition of cobble stones appearing on the sea surface in the port for over 15 years until August 2018 after the cobble stones have been removed by dredging work on May 2003. In order to explain this, the study team has researched conditions that existed before November 28, 2002 when the deposition suddenly appeared and did not exist after May 2003 when the cobble stones were removed. It is turned out that the temporary construction road meets the conditions.

For the construction of the breakwater and transportation of wave dissipating blocks to be installed in front of the breakwater, the temporary road was constructed across the Choiseul river mouth (see Photo 6-40, Photo 6-41) up to the root of the breakwater (see Figure 6-22). The temporary road was still present as of December 2002. However, after the completion of the Choiseul fishing port on May 2003, the temporary road should have been removed.

Photo 6-40 Temporary construction road at Choiseul river mouth

Photo 6-41 Temporary construction road and drainage

Figure 6-22 Estimated location of temporary construction road (Photo: Google Earth May 4, 2006)

Regarding the temporary road, Japanese engineer from MIRAI CONSTRUCTION CO., LTD., who stationed at the Choiseul fishing port construction site at the time, left a note quoted in Table 6-6. The fact that the wave height exceeded 1.0 m by the hurricane Lili on September 23 is consistent with the wave hindcasting result shown in Figure 6-20. The eroded area mentioned in the note as "for temporary road along the shoreline to the root of breakwater" is not the river mouth but the area parallel to the shore from the right side of river mouth to the root of the breakwater. After September 2002, to avoid a flooding, a part of the temporary road crossing the river mouth was artificially destroyed by excavating several times. The high waves corresponding to words in the note based on the visual observation "from the beginning of November 2002, the days where the wave height reaches 60 cm to 80 cm and sometimes reaches 100 cm at the Choiseul site continued" is not consistent with the hindcasted results shown in Figure 6-20. However, it can be regarded as a fact that the rehabilitation works for temporary road was repeated almost every two days from the beginning of November. From the above, the temporary road is supposed to be eroded many times from late September to November.

Table 6-6 Notes by Japanese engineers

From September 21 to October 4, 2002
Hurricane LILI (wind speed: 125 knot, atmospheric pressure: 938 hpa, category 4) occurred and waves of visual class 3 (more than 1.0 m) were recorded on September 23. At this time, the filling sand that were placed for temporary road along the shoreline to the root of breakwater was eroded by the waves. Sand that was washed into the sea was dredged (only within the range of the radius of the backhoe near the shoreline) and filling sand was placed again after the damage.
Since September 2002
There were heavy rainy days. In order to avoid the flood, the temporary construction road was excavated many times and artificially destroyed. Sand and stones which were washed out were used for restoration, and no materials were brought from outside.
From the beginning of November 2002
The days where the wave height reaches 60 cm to 80 cm and sometimes reaches 100 cm at the Choiseul site continued. The temporary road collapses due to the waves, so rehabilitation works were continued almost every two days.

The material for the temporary construction road is considered to be soil nearby. Photo 6-42 is an aerial photograph of 1941, 2004 and 2009. Focusing on the yellow frame, it was covered with plants as of 1941 before the construction of the fishing port. Vegetation cannot be seen in 2004, about a year after the construction of the fishing port. The temporary road was laid from this location to the root of the breakwater as shown in Figure 6-22. From these factors, it is inferred that the materials of temporary road were soil collected from the area squared by the yellow frame. Therefore, because the geology of this place consists of pumice flow deposits, it is considered that the material contained cobble stones of low specific gravity. Given that cobble stones of extremely low specific gravity (pumice: specific gravity 1.06, see Table 6-2) was included, the following situation can be assumed.

Temporary road was repeatedly eroded by the effects of waves from the beginning of November 2002, and pumice stone was washed out. Since flow along with waves is oscillatory flow, exaggeratedly speaking, pumice remains in the shallow area close to the swash zone. After that, it is transported to the fishing port by obliquely incident waves. There is no filling sand containing pumice even in the river mouth and around shoreline up to the root of the breakwater because the temporary road has been removed after the completion of the Choiseul fishing port. Therefore, if pumice is supplied, it is transported from the upstream in case of a flood. However, since the water flow is unidirectional, in other words, not oscillatory flow, the pumice which is washed out of the river mouth can be carried further offshore areas so that such pumice cannot remain at a coastal area. As a result, it is not transported to the fishing port now.

Inferring as above, the facts that the cobble stones was once deposited in the fishing port in November 2002, the deposition moved toward the interior of the port, and there is no deposition after completion of the construction can be explained. Since there is not enough data, further inference is difficult. This inference is regarded as correct until the contradictory data will be found out. In short, deposition of the cobble stones in the port is caused due to the special condition of temporary road, thus it is not taken into consideration for the countermeasures.

Photo 6-42 Choiseul Aerial Photography (1941, 2004 and 2009)

6.4 Condition until constructing additional breakwater

6.4.1 The process of deposition at Choiseul fishing port and surrounding sand budget

For 1,211 days from November 30, 2002, two days after confirming the deposition in the port, to March 24, 2006, the deposition topography in the port was surveyed 50 times to monitor the conditions. During this period, the dredging works summarized in Table 6-7 were conducted. The results of this monitoring are summarized in the report [2),]so only the necessary parts are quoted (“ ”) in the following.

【Reference】

[2)] ECOH CORPORATION: Proposal of the study for sedimentation mechanism and the maintenance method in Choiseul fishing port, page 23, August 2006

Table 6-7: Results of dredging in the port

Dredging term	Amount（m^3）
May 10 to 24, 2003	700
May 3 to 17, 2004	800
July 2 to 9, 2004	2,500
September 20 to October 22, 2004	1,800
August 10 to 24, 2005	870
February 20 to March 20, 2006	2,500
Total	9,170

The process of deposition in the port is described as follows.

“① Shallow water like corridor shape is generated in front of west breakwater by the littoral drift from offshore.

② With this corridor the longshore current to head through front of the breakwater is generated.”

The further description from here refers to Figure 6-23. Figure 6-23 shows the location of the -1 m contour lines from December 6, 2002 to January 4, 2004. During this period, 700 m^3 dredging work is conducted in one time in May 2003.

“③ Sand is moved with this longshore current and sand sedimentation is generated making the rounds of breakwater head

④ The sedimentation area in harbor firstly is limited to right behind the breakwater and getting on to inside of harbor (slipway side).

⑤ When the sedimentation length of inside of breakwater becomes about 50 m the sand sedimentation goes to inside of harbor and at the same time, the sedimentation also get on to center area of harbor

⑥ Waves become easier to enter into harbor by the wave refraction at the harbor mouth due to the shoal of harbor mouth”

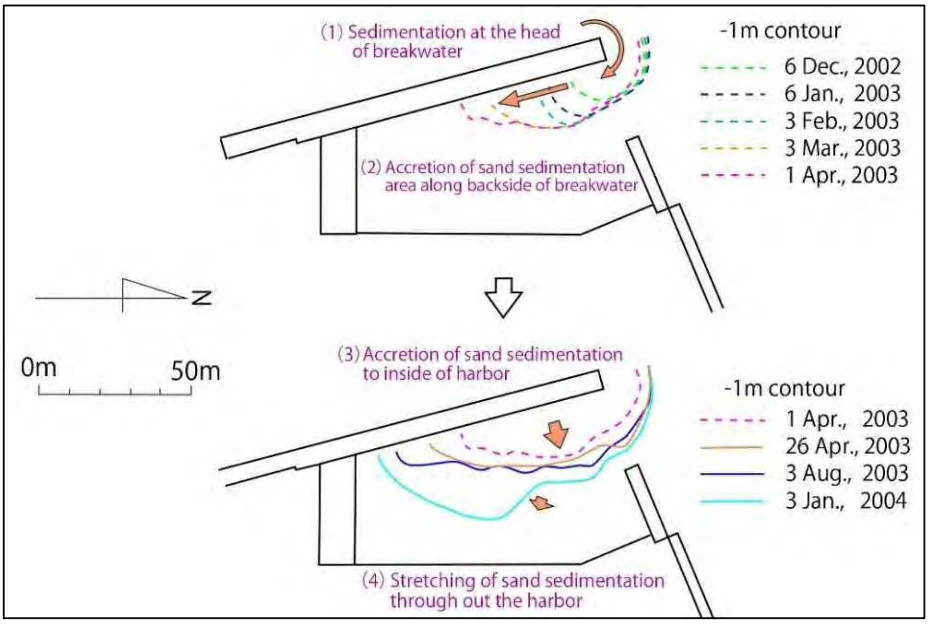


Figure 6-23 Deposition process in the port

Based on this explanation, the sand budget of the Choiseul fishing port compiled by the report is as follows.

"As the result of 3 years observation, it is considered that the sand about 6,000～10,000m^3 per year is transported along the breakwater, the sand about 2,500～3,000m^3 per year is deposited in the harbor mouth and the basin of Choiseul fishing port and the sand about 3,500～7,000m^3 is supplied toward northern area."

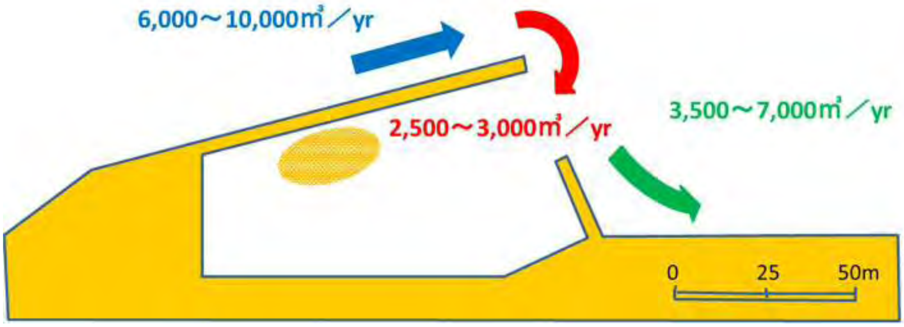


Figure 6-24 Sand budget around the Choiseul fishing port

The sand budget stated in the report is illustrated in Figure 6-24. Unfortunately, the report does not provide evidence of these quantities. However, the validity of the amount of deposition in the port was confirmed by examining the data in the report. Figure 6-25 shows the changes of the estimated amount of the deposition in the port based on 50 monitoring data. Although the amount of the deposition gradually increases at the beginning, it has been almost constant since March 2004. In other words, the dredged amount and the amount of sand inflow to the port can be regarded as balanced. Then, dredging works of 9,170 m^3 was carried out during the monitoring period for 1,211 days, so the amount of sand inflow to the Choiseul fishing port per year is

$$9,170\ m^3 \times 365\ days / 1211\ days = 2,764\ m^3 \qquad (1)$$

From this point of view, the assessment that 2,500 m^3 to 3,000 m^3 deposited annually in the entrance and inside of the Choiseul fishing port is appropriate.

The validity of remaining two quantities, the rate of longshore sand transport in front of the breakwater and the amount supplied to the north beach, cannot be confirmed in the data stated in the report. However, as for the longshore sand transport rate in front of the breakwater, its validity could be confirmed by analysis using other data. The contents are described later in 6.7.

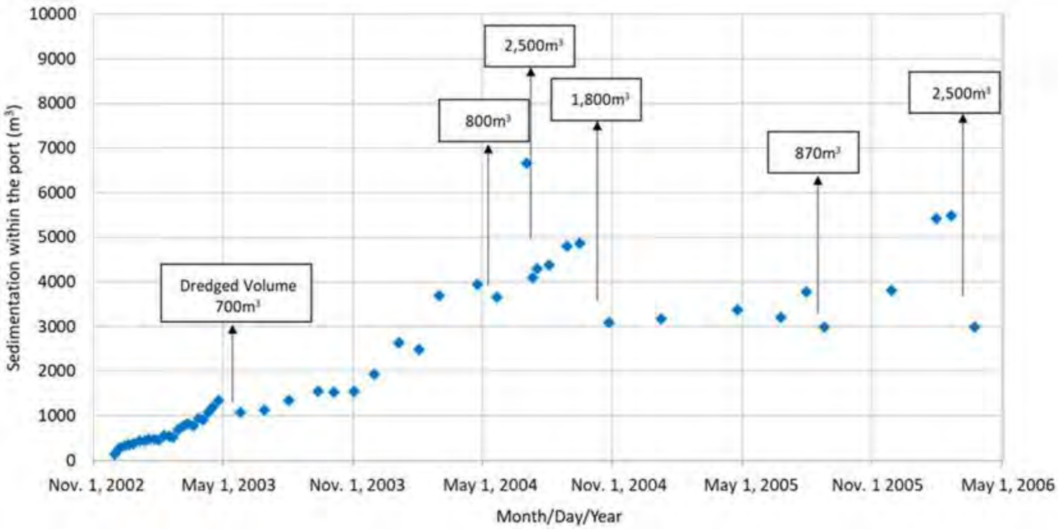


Figure 6-25 Changes in the amounts of deposition in the port and dredging

In Photo 6-43, the fishermen are standing beside the fishing boat and pushing it, so it can be easily assumed that the port entrance is quite shallow. Two fishermen are outboard and another one is adjusting the angle of outboard motor with its propellers turning slowly. Looking at -1 m contour lines in Figure 6-23, it is clear that vicinity of the groin where the fishing boat is sailing, where the green beacon light is installed, is the deepest at the port entrance. At this time, the deposition occurred in the port as seen in Photo 6-44.

Photo 6-43 The fishing vessel returning to the port in August 28, 2004

Photo 6-44 Deposition in the port in August 28, 2004

The movement of the deposition before the construction of the additional breakwater is inferred, and is shown in a schematic diagram in Figure 6-26. The sand transported to the northward along the breakwater can be divided into two: sand which diffracts into the port at the breakwater tip (A) and sand that is transported further to the north (B). Then, sand that causes the deposition in the port diffracts around the breakwater tip and then is carried into the port along the breakwater. The point is that the sand inflow into the port can take only one course which diffracts around the breakwater tip.

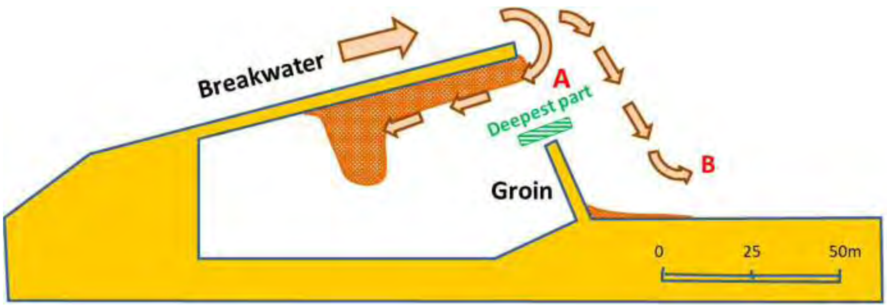


Figure 6-26 Schematic diagram of sand transport before construction of additional breakwater

6.4.2 Mechanism of sand transported into the port

The mechanism of sand transport that sand is carried from the port entrance and gradually transported to the interior along the breakwater is considered from two standpoints: suspended sand movement and bed load movement. The fluid motion to be a major external force effecting sand movement around the coast and fishing port is currents and oscillatory flows due to waves. In general, the former currents carry suspended materials and the latter carry bed load as described below.

(1) Possibility of suspended sand movement

Since the port pond is calm, it is unlikely that the sand is re-suspended after such sand is once settled. Therefore, for further transportation to the interior of the port, the suspended state must continue from the port entrance to the interior of the port. Assuming that the particle size of sand is 0.2 mm, the underwater settling velocity is 3.5 cm/s estimated by the Stokes equation. Hypothesizing that the water depth in the pond is 2 m, it takes 57 seconds for sand particles suspended near the surface to settle on the seabed. Flow velocity of 1.75 m/s is necessary to transport suspended sand about 100 m from the port entrance to the interior of the port within the period.

Possibly there exist tidal currents, nearshore currents, oscillatory flows caused by long period waves, and oscillatory flows caused by waves. The former two can be regarded as currents. The long-period waves have two characteristics of both currents and oscillatory flows. Then, excluding oscillatory flow due to waves, below part deals with the three types of currents and a flow.

【Tidal currents】

The maximum tidal current velocity at the port entrance is approximately estimated. The estimation conditions are: the tide range is 16 cm, the period is 12 hours, the mean water depth is 2 m at the port entrance, and the current velocity changes sinusoidally. As a result, the estimated maximum current velocity is 0.11 cm/s. Although there exists slight ambiguity in the settings of the mean water depth at the port entrance, the velocity can be doubled (0.22 cm/s) in case that the mean water depth is 1 m, and it can be corrected to 4 times (0.44 cm/s) when the mean water depth is 0.5 m. As a result, it can be understood that even the maximum velocity is not enough to transport the suspended sand to the interior of the port.

【Nearshore currents】

Figure 6-27 shows the results of numerical simulation of the nearshore currents around the Choiseul fishing port. The minimum current velocity represented in vectors in this figure is 5 cm/s. The nearshore currents occur around the Choiseul fishing port, and there is no current intruding into the port. Also, at the port entrance, there is no noticeable current into the port, and the current velocity inside the port is less than 5 cm/s. Therefore, even if suspended sand is transported into the port by the nearshore currents, the amount is extremely small and the sand cannot be carried to the interior of the port.

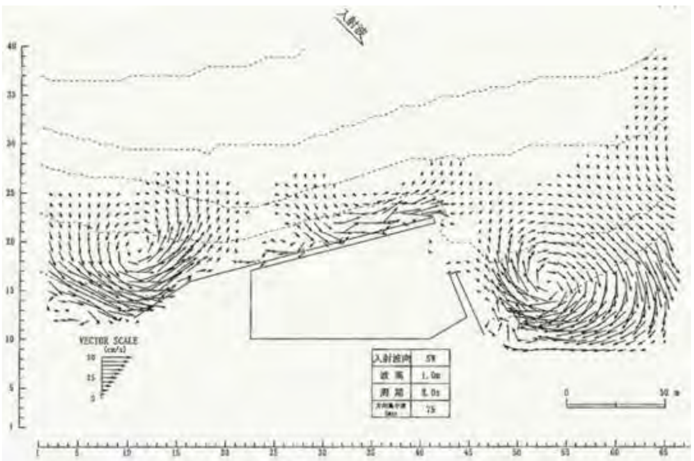


Figure 6-27 Results of numerical simulation of nearshore currents
(considering sedimentation on the front of breakwater) [3)]

【Long-period wave】

Figure 6-28 shows the currents distribution of the long-period waves (in case the velocity in the port direction is the strongest). Since the minimum velocity indicated in vectors is 1 cm/s, the velocity is less than 1 cm/s in most areas in the pond. Therefore, the currents caused by long-period waves cannot transport suspended sand to the interior of the port as well.

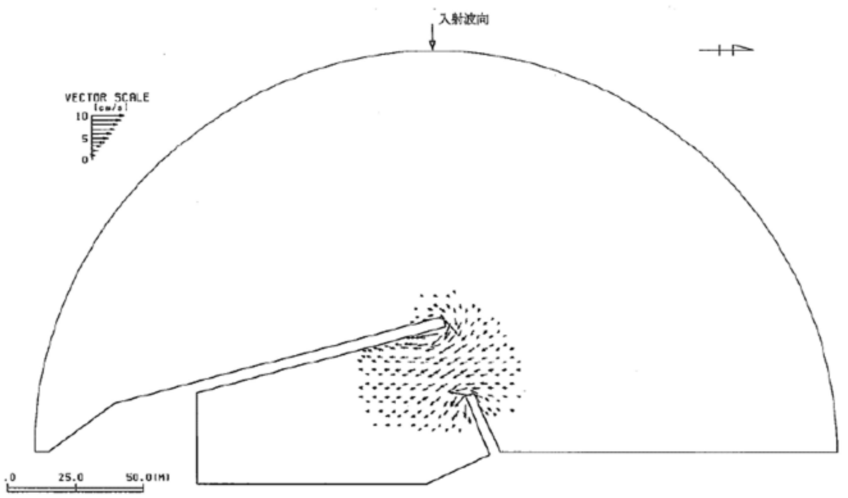


Figure 6-28 Distribution of flow due to long-period waves
(maximum velocity in the port) 4)

(Wave direction: W, wave height: 1 cm, period: 125 seconds, wave dissipating structure fully in the port)

Furthermore, since long-period waves also have the characteristics of oscillatory flow, the potential of the oscillatory flow to carry suspended sand is briefly studied. When the water depth in the pond is 2 m, the excursion length of water particles by standing long-period waves (period: 125 seconds) at the port entrance is $\xi = 44.0$ H (m). Details of the derivation in the equation is omitted. Where, H is the wave height of the long-period waves. When 1.2 cm as the long-period wave height is applied, the amplification factor in the port is assumed to be 1.2, which is a condition in the preliminary evaluation 4), then $\xi = 0.53$ m is obtained. In other words, the suspended sand at the port entrance is transported into the port at a maximum of 0.53 m during one period of a long-period wave, and such suspended sand settles within this range. That is, the excursion length of water particles by long-period waves cannot sufficiently explain the actual deposition phenomenon at the interior of the port.

Based on the above consideration, it is possible to deny the hypothesis about the deposition mechanism in the pond, that is "suspended sand is carried by the flow into the port and deposited". Furthermore, this hypothesis contains the following contradiction. That is, the water depth becomes shallower as the deposition goes on, and it shortens the time that suspended sand settles. As a result, suspended sand settles before reaching the interior of the port. In other words, the deposition of suspended sand gradually approaches the port entrance in accordance with time, thus there is a contradiction to the fact that the sand deposition site gradually moved toward the interior of the port.

(2) Possibility of excursion of bed load

Figure 6-29 shows the critical velocity (the velocity lower than this does not transport bottom sand) for sand with the particle sizes of 0.1 mm and 0.2 mm of which approximate values were calculated by the Shields formula. Although the critical velocity changes depending on the particle size and the water depth, in the following, the critical velocity of 15 cm/s is considered as a reference.

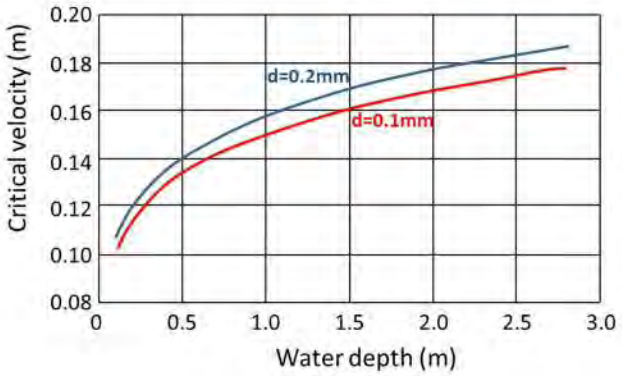


Figure 6-29 Critical velocity of sand

First, the approximate values of the flow examined in the previous section are as follows.

- Tidal current: maximum velocity at the port entrance, 0.7 cm/s
- Coastal current: from the port entrance to the whole area of the pond, less than 5 cm/s
- Long-period wave: maximum flow velocity around the port entrance, approximately 5 cm/s

All of them are lower than the critical velocity. In other words, these flow and currents cannot transport sand on the seabed in a state of bed load.

Figure 6-30 shows the relationship between the critical wave height of wind waves with periods of 5 seconds and 7 seconds and the water depth. The critical wave height is a wave height at which the maximum flow velocity at the seabed is 15 cm/s, which is the critical velocity of sand movement when the oscillatory flow caused by waves is sinusoidal. In a case of waves with a period of 5 seconds, at a water depth of 3 m, a wave height of 20 cm is the minimum wave height (critical wave height) for transporting sand on the bottom. The critical wave height becomes lower as the water depth decreases, and the critical wave height is 15 cm, 10 cm and 7 cm respectively in cases that the water depth is 2 m, 1 m and 0.5 m. Such waves can occur in the pond. In other words, sand can possibly be transported by waves in the pond.

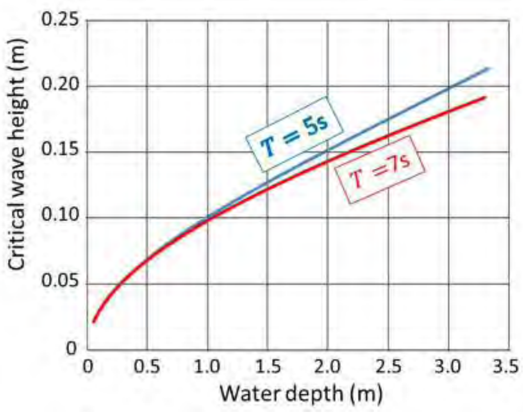


Figure 6-30 Relationship between critical wave height for sand movement and water depth

Further conditions are needed so that the waves transport sand to the interior of the port along the breakwater. One of the conditions is that the oscillatory flow by waves is a reciprocating flow, so it is pointed out that even if the flow velocity at the seabed exceeds the critical velocity, it only moves the bottom sand back and forth and excursion does not actually occur. Such a point has to be cleared. In fact, when the oscillatory flow by progressive wave effects on the seabed, net excursion of the bottom sand occurs in the state of bed load to the same direction as the wave propagation. The reasons of occurrence of the net excursion are illustrated conceptually in the appendix.

The other condition is the existence of waves along the breakwater transporting sand to the interior of the port, since the sand is transported to the same direction as the wave propagation. Figure 6-31 shows the distribution of wave directions which have been already calculated. From this figure, the distribution of wave direction that intrudes to the port can be seen. The wave after diffraction around the breakwater tip propagates to interior of the port hitting against the breakwater rather than along the breakwater. This situation corresponds to sand being transported along the breakwater to the interior of the port.

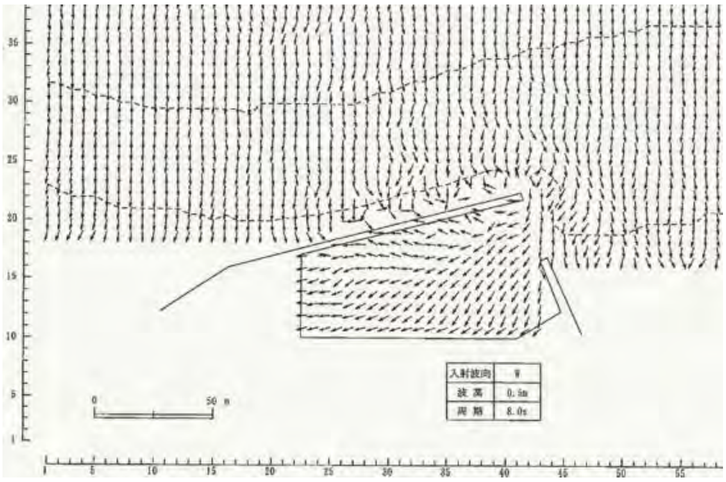


Figure 6-31 Results of numerical calculation for distribution of wave direction (considering sedimentation on front and back of breakwater) [3]

In case of bed load, sand moves forward and backward as a wave passes by, and as a subtraction, net sand excursion occurs in the same direction as the wave propagation. For example, even if the net excursion of sand transported in the wave propagation is 0.1 mm per one wave period, sand can be transported 1.7 m in a day toward the interior of the port since the daily number of waves with the period of 5 seconds is approximately 17,000.

Comparing Figure 6-27 (nearshore currents) and Figure 6-31 (waves), the difference is clearly shown: the nearshore currents do not come into the port, but the waves propagate into the port.

From the above, it is considered that the sand excursion to the interior of the port occurs in the state of bed load.

【Reference】

[3] Report of the study for sedimentation mechanism and the maintenance method in Choiseul fishing port, ECOH CORPORATION, February 2005.)

[4] Basic design study report on the project for coastal fisheries development in Saint Lucia, January 2001

6.5 Construction of additional breakwater and related increase in the amount of deposition

6.5.1 Actual condition of deposition

From April to July 2008, an additional breakwater of 40 m long was constructed at the tip of the breakwater at an angle of 45° in order to prevent the deposition in the Choiseul fishing port (see photo 6-48 to be explained later). The expected function of the additional breakwater is to trap the sand to be transported in the port around the breakwater tip and reduce the amount of the deposition in the port.

Photo 6-45 and 6-46 were taken just a month after the construction of the additional breakwater was completed. At the same time, the deposition in the pond was removed by dredging work. Looking at the air bubbles and ship waves generated by the propellers of the outboard motors attached on the fishing boat, it can be understood that the fishing boat is operated at a high speed. In other words, the port entrance was kept in good condition.

Photo 6-45 Choiseul fishing port on September 29, 2008

Photo 6-46 Port entrance on September 29, 2008

However, the condition changes significantly after that. Photo 6-47 and 6-48 show the conditions approximately nine months after the construction of the additional breakwater. It is unclear whether a dredging work was executed or not during this time. In Photo 6-47, two fishermen are pushing the fishing boat to enter the port. The deposition seems to progress considerably. It should be noted that the fishermen are pushing the fishing boat and passing near the center of the port entrance. Before the construction of the additional breakwater, fishermen passed near the tip of the groin (see Photo 6-43). In other words, the relatively deep place where fishing boats can pass changed from the area close to the groin to the central area of the port entrance due to the construction of the additional breakwater. In Photo 6-48, the deposition occurs inside the groin. Deposition in this area was not found before the construction of the additional breakwater (see Photo 6-44). Furthermore, according to Photo 6-48, deposition also occurs on the outer side of the groin, and the shoreline advances forward. The advance of the deposition and shoreline outside the groin did not occur without the additional breakwater (Photo 6-43) and right after the construction of the additional breakwater (Photo 6-46).

Photo 6-47 The fishing boat returning to the port (May 9, 2009)

Photo 6-48 The port entrance (May 9, 2009)

As of September 29, 2009, deposition in the pond disappears as seen in Photo 6-49. Probably, a large-scale dredging work was implemented between May 9 and September 29, 2009. About two months later as shown in Photo 6-50, although there is a slight deposition below the sea surface backside the breakwater, neither deposition at the port entrance nor advancement of the shoreline on the north beach is confirmed.

Photo 6-49 Choiseul fishing port on September 29, 2009

Photo 6-50 Choiseul fishing port (Google Earth; November 23, 2009)

There has been no data available about the deposition of the Choiseul fishing port for about last six years. However, as deeply stated later, the hurricane Tomas hit on October 30, 2010 causing a record heavy rain in Saint Lucia.

Approximately 6 years later, on September 27, 2015 as shown in Photo 6-51 and November 4, 2015 as shown in Photo 6-52, the port entrance is completely closed and some fishing boats are pulled up on the beach outside of the port. The yellow backhoe seen in the Photo 6-52 had been provided by Japan to dredge the port entrance. However, at this time it has already been deteriorated and unusable.

Photo 6-51 Choiseul fishing port (Google Earth; September 27, 2015)

Photo 6-52 Port entrance completely blocked on November 4, 2015

Figure 6-32 is a schematic drawing showing the conditions that sand is transported into the port after the construction of the additional breakwater considered from the above. The transported sand along the breakwater is divided into two: sand diffracting around the breakwater tip into the port (A), and sand going further.

A part of the sand passing (B) is transported to north as before, but the rest is deposited on the beach and the shoreline moves forward. When the shoreline advances to the tip of the groin, sand (C) is transported around the groin tip into the port. Then, a new deposition place appears inside the groin. Before the construction of the additional breakwater, there was only one sand inflow path, whereas sands are transported into the port through two paths after the construction. In this way, it is easy to understand that the deepest part of the port entrance is the central part.

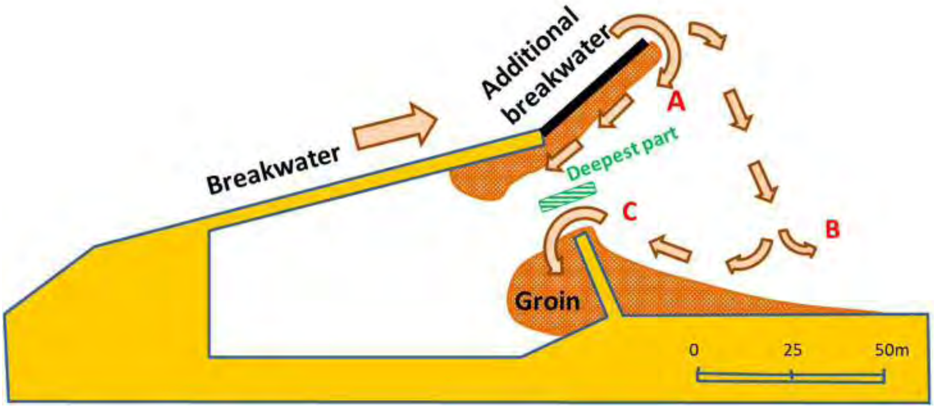


Figure 6-32 Schematic diagram of sand transport after construction of additional breakwater

6.6 Beach deformation on the north side from Choiseul fishing port (Sabwisha Beach)

6.6.1 Influence of construction of Choiseul fishing port on the northern Coast

Figure 6-33 shows shoreline changes for some years, which read from aerial photographs, based on 1941. Construction of the Choiseul fishing port began on January 31, 2002, and the breakwater has been completed by November 2002.

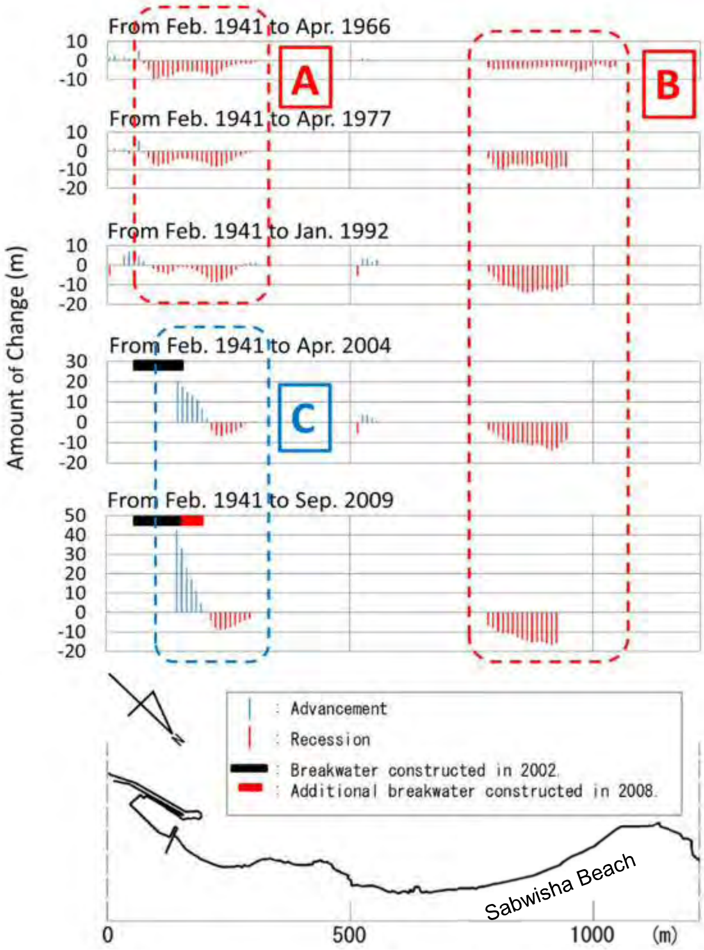


Figure 6-33 Shoreline changes read from aerial photographs

Attention is paid especially to the beach changes on the north side of the Choiseul fishing port. Beach process is divided into three regions and times (A, B, C in the figure). Erosion of region A occurs before the construction of the fishing port and therefore is not due to the construction of the fishing port. Erosion occurs also in the B region, which is the Sabwisha Beach (see Photo 6-53). However, since the erosion is recognized before the construction of the fishing port, it is not due to the construction of the fishing port. In other words, the erosions in the reasons of A and B are the result of natural fluctuations. On the other hand, the beach deformation in the area and time C occurs after the construction of the Choiseul fishing port, which is a typical change in which sand deposits in the shield area of the breakwater.

From the above, it can be said that the influence of the construction of the Choiseul fishing port on the surrounding (Northern beach) is locally limited to the area and time C.

Photo 6-53 Sabwisha Beach

6.6.2 Recovery of Sabwisha Beach

At Sabwisha Beach as shown in Figure 6-33, B, the shoreline always recedes in comparison with the shoreline in 1941. Possibility of beach recovery in the future in relation to the Choiseul fishing port is considered. In order to understand the beach process of Sabwisha Beach, it is very useful to review the beach process of Anse La Raye whose actual situation has already been reported [5].

【Reference】

[5] JICA and ECOH: Follow-up Cooperation Study Report on the Project for Improvement of Fishery Infrastructure in Anse La Raye, Saint Lucia, page 3-11～3-16, March 2013.

Anse La Raye is located approximately 18.4km north of Choiseul fishing port in a direct distance as shown in Figure 6-34. The beach of Anse La Raye had its shoreline receding at a constant speed of 0.5m/year since 1966. As a result, waves acted directly on a part of the fishery complex (Photo 6-54, a green roof on a sandy beach) developed with the assistance of JICA as seen in Photo 6-54. Therefore, in September 2011, JICA conducted a survey for formulation of countermeasures against erosion and protection of the fishery complex. The conclusion is that "Because the beach will recover slowly, in other words, sand deposits from now on, thus basically nothing needs to be done. However, since the current beach is very thin, temporary emergency measures are necessary ".

Photo 6-55 is the condition of the beach of Anse La Raye about seven years later. No artificial treatment such as artificial beach nourishment has been added. As expected, sandy beaches have returned to nature on beaches where erosion has gradually progressed for several decades.

Figure 6-34 Location of Anse La Raye

Photo 6-54 Anse La Raye Beach on September 3, 2011

Photo 6-55 Recovered Anse La Raye Beach on August 26, 2018

The reason why the JICA study team in 2011 judged that "the beach will recover slowly from now on, so basically you can do nothing" is as follows.

Figure 6-35 shows the daily rainfall observed at Hewanorra International Airport (see Figure 6-34). A record heavy rainfall of about 600mm has occurred on October 30, 2010, about a year before the JICA survey. This is due to the hurricane Tomas. The amount of rainfall is estimated to be once in 180 years. And large and small-scale landslides and hillside collapses occurred everywhere in St. Lucia (see Photo 6-56). Then, the sand that flowed out from the river flowing into the Anse La Raye bay deposited on the seabed in front of the river mouth as shown in Figure 6-36. The 2011 JICA survey confirmed this sand on the seabed, and it is speculated that sand deposited will be slowly transported to the shore by the action of subsequent waves and landed to the beach, so it is concluded that the beach will recover naturally.

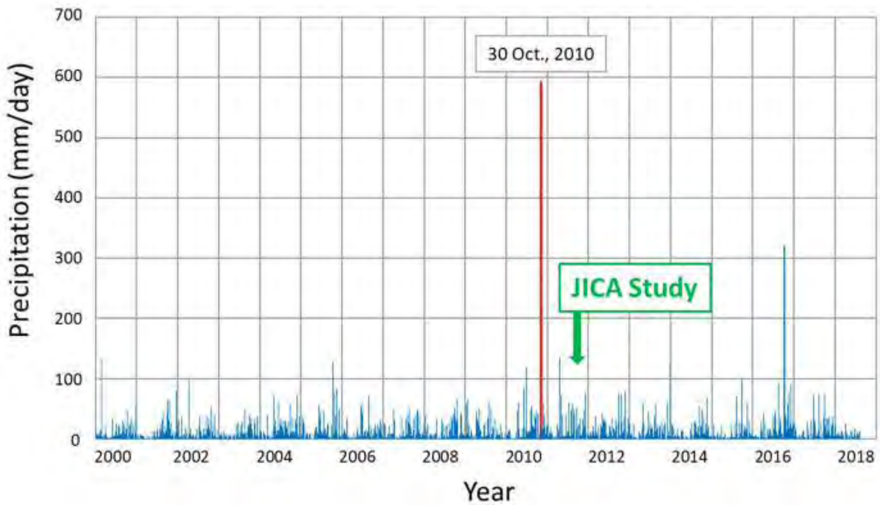


Figure 6-35 Rainfall (Hewanorra International Airport)

Photo 6-56 Massive hillside collapse due to hurricane Tomas

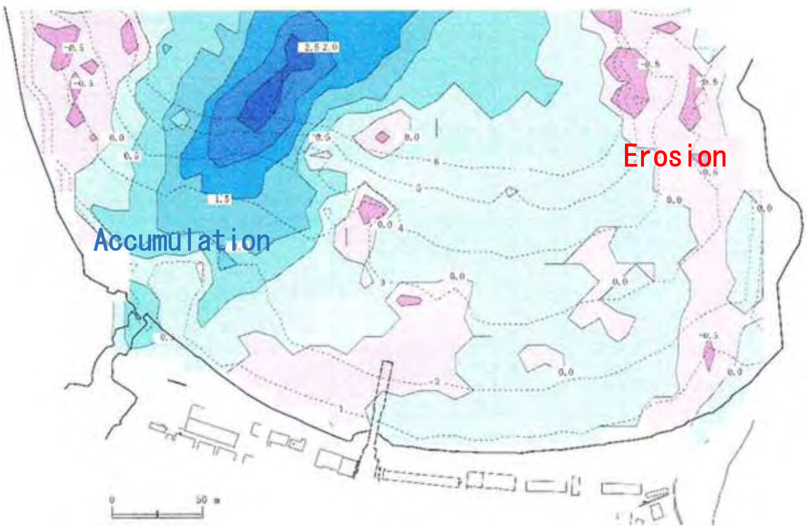


Figure 6-36 Anse La Raye bathymetric change from October 20, 2006 to September 8, 2011

The Choiseul fishing port is located approximately 18.4km south of Anse La Raye as shown in Figure 6-34. The basin area of the Choiseul river, which supplies soil to the sea, is 4.33km^2, and the basin area of the Anse La Raye River is 5.24km^2. Since their scales are similar, it is thought that a large amount of soil flowed out of the Choiseul river at the time of the hurricane Tomas.

Then, even at the eroded Sabwisha Beach, it can be inferred that the sand flowed out of the river by the hurricane Tomas on 30 October 2010 has been deposited on the seabed in front of the mouth, then drifted in the longshore northward direction by waves, and resultantly the Sabwisha Beach has recovered. However, since Sabwisha Beach is located about 900 m north from the mouth of the Choiseul river, the sand has to be transported from the mouth to the beach for the beach recovery. A delay of recovery occurs in the beach because of the distance. Also, effects by the Choiseul fishing port, which is built in the middle of the route to Sabwisha Beach, are added.

From Figure 6-33, the amount of shoreline changes at La Pointe Beach are estimated;

February 1941 to April 2004 : The shoreline recedes about 10m (about 0.16m/year),

April 2004 to September 2009 : The shoreline recedes approximately 2m (approximately 0.4m/year).

Figure 6-37 shows the change of the shoreline of La Pointe Beach from November 2009 to March 2018 read from Google Earth. From this figure, it is said,

November 2009 to September 2015: The shoreline recedes about 5m (about 0.9m/year),

September 2015 to March 2018 : The shoreline accretes about 7m (about 2.8m/year).

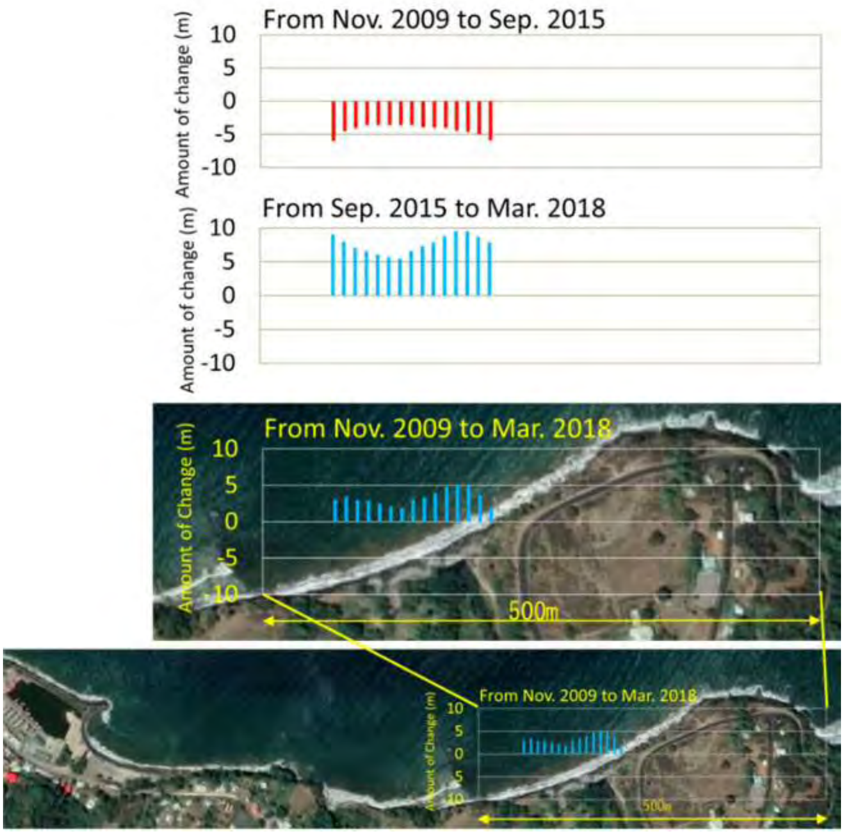


Figure 6-37 Changes of the shoreline of Sabwisha Beach
(November 2009 to March 2018)

Figure 6-38 shows the construction terms of the Choiseul fishing port, dredging term by backhoe, rainfall and the rate of shoreline changes in Sabwisha Beach. Looking at Figure 6-38 with understandings that effects on shoreline change at Sabwisha Beach caused by the artificial factors including the construction of the Choiseul fishing port and sand provision from the Choiseul river appear approximately 5 years later, the cause of increase in recession rate from 2004 to 2009 is regarded as effects by construction of the Choiseul fishing port, and the cause of further increase in recession rate from 2009 to 2015 seems to be construction of the additional breakwater. Furthermore, accretion of shoreline from 2015 to 2018 seems to have occurred after a sand discharge from the river due to the hurricane Tomas.

Sand has been being taken out of the sedimentary system by maintenance dredging by backhoe since the end of 2016. Especially recently, more sand than before has been being dredged by the improved method, therefore some effects on Sabwisha Beach seem to appear in a few years.

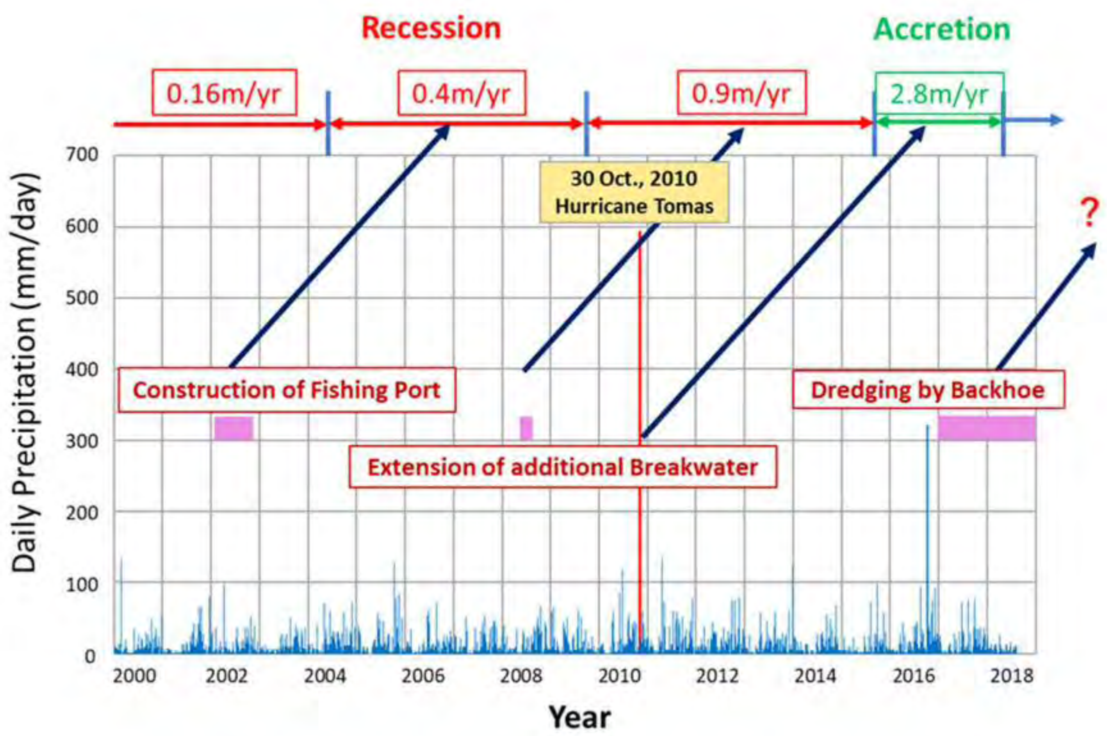


Figure 6-38 The construction of the Choiseul fishing port and changes in the shoreline of Sabwisha Beach

6.7 Contribution ratio of river-origin and sea cliff-origin sands on deposition in the port

Probably any objections are not given to the understanding that the sources of sand deposited in the port are the Choiseul river located at the south of the port and the sea cliff extended to south (Photo 6-57 and Photo 6-58). However, opinions are divided as to the biggest source of the sand in the fishing port.

It is generally too expensive and impractical to take countermeasures against the deposition by cutting off the sand supply source. Whichever the biggest sand source is, countermeasures to prevent deposition have to be made at (or near) the Choiseul fishing port. For this reason, it seems that the argument on which source is superior is meaningless. However, hopefully the sand source is identified because it contributes to comprehend the sand transport mechanism in southwest area of Saint Lucia. Organizing the available data and inference based on past experiences, ratio of the supply source to deposition in the Choiseul fishing port is considered.

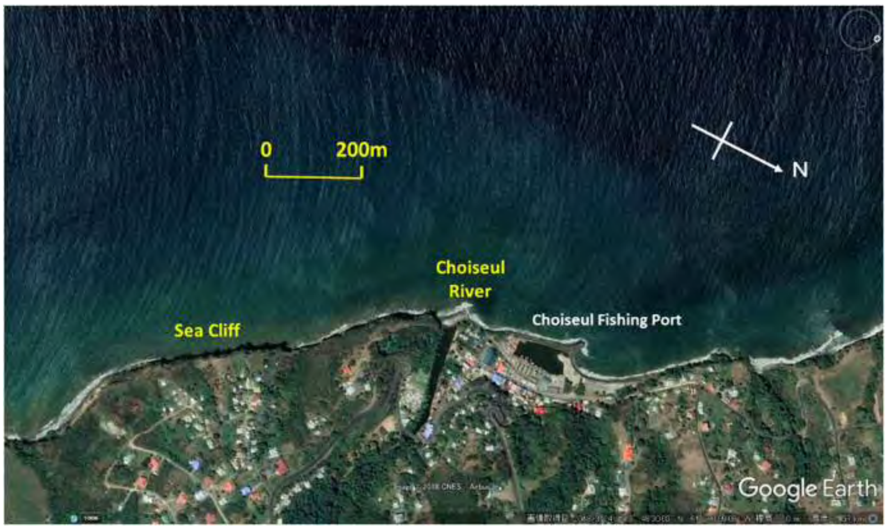


Photo 6-57 Choiseul fishing port and sea cliff

Photo 6-58 South Sea Cliff of the Choiseul fishing port
(Drone photo, 25 November 2017)

The contribution rates of the two sand sources were examined by the following two methods.

①Method by estimating the amount of sand discharged from the Choiseul river and the amount from the sea cliff and inferring the contribution rate.

②Method by X-ray fluorescence analysis of sand collected from three areas, the upper river area, sandy beach at the base of sea cliff and sandy beach in front of the west breakwater in the Choiseul fishing port, and examining metal oxides of two sand sources to the sedimentary area and estimating contribution ratio from mixing rate.

6.7.1 Estimation for volume of sand supplement

(1) Sand volume discharged from the Choiseul river

Sand volume discharged from the Choiseul river is evaluated referring to two methods based on available data and experiences in Japan, and another method based on the result of analysis on sand discharged from a river in the similar size. However, there is little data on the Choiseul river. For this reason, inevitably, it is quite roughly evaluated.

【Empirical method 1: Estimation by transport sand concentration】

Annual sand discharged from rivers Q (m^3/year) can be estimated by following formulae [6];

$$Q = C_f \cdot q \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots (3),$$

$$C_f = 5.5 \cdot \tan^2\theta \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots (4),$$

$$q = C \cdot r \cdot A \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots (5),$$

where,

$\tan\theta$: riverbed slope (1/29),

q : annual discharge (m^3/year),

C : runoff coefficient (=0.5)

r : 2,440 mm; annual precipitation (sum of the average monthly rainfall from 1991 to 2015 referred Climate Change Knowledge Portal [7])

A : drainage area (referred Digital Globe [8]): 4.33 km^2.

When these quantities are taken into calculation,

$$\text{Annual sand discharge } Q \fallingdotseq 3{,}430 \ (m^3/\text{year}) \quad \cdots\cdots\cdots\cdots (6)$$

is obtained.

【Empirical method 2: Estimation from annual average specific runoff sand volume】

As shown in Figure 6-39, it is empirically known in Japan that there is a relationship of equation (7) between q_s and A [6];

$$q_s = K \cdot A^{-0.7} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (7),$$

where,

q_s : annual average specific sand discharge per unit drainage area (m^3/km^2/year),

A : drainage area (km^2),

K : constant.

The straight line ① in the figure 6-39 is the river with the largest volume of sand discharge in Japan, and straight lines ② to ③ are the rivers considered to have a large volume of sand discharge. Straight lines ④ to ⑤ indicate rivers with little sand discharge, straight line ④ indicates the upper limit, straight line ⑤ indicates the lower limit, and many other areas also fall between straight lines ④ to ⑤. The annual average specific sand discharge of the Choiseul river is estimated by the straight lines ④ and ⑤.

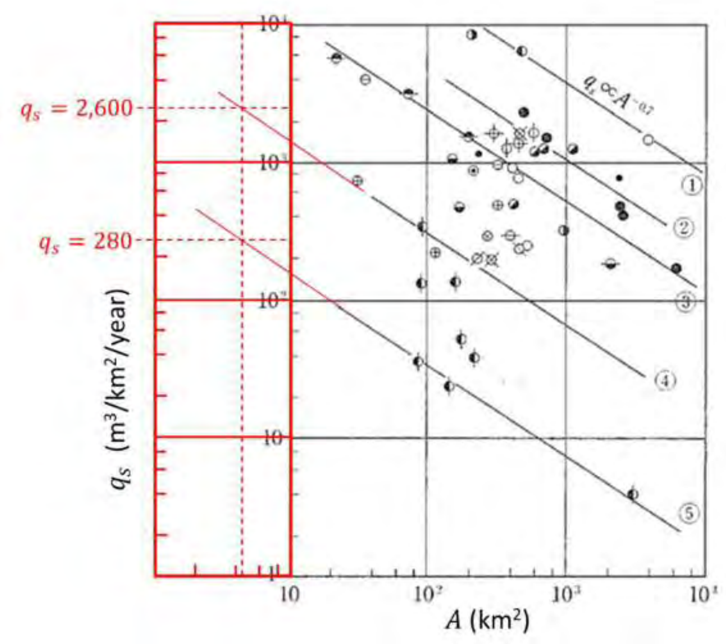


Figure 6-39 Relationship between q_s and A [6)]

However, since the constant K is not dimensionless, equation (7) cannot be universally applied to various rivers. In addition, the empirical formula is based on river data with a drainage area of 20 to 6,000 km^2. On the other hand, the Choiseul river is not a Japanese river, and the drainage area is just 4.33 km^2, so it is somewhat unreasonable to apply the empirical formula. With understanding this restriction, the annual sand discharge, Q, is estimated.

Since the annual specific sand discharge, q_s, is the sand discharge per unit drainage area, the volume of sand discharge of the whole drainage of the river is following,

$$\text{Annual sand discharge } Q = q_s \cdot A \qquad \cdots\cdots\cdots\cdots\cdots\cdots (8).$$

Since the drainage area is outside the range of the original graph (colored in black) in Figure 6-39, graph drawn in red is supplemented and straight line ④ and straight line ⑤ is extrapolated, below result is obtained.

$$q_s = 280 \sim 2{,}600 \qquad \cdots\cdots\cdots\cdots\cdots\cdots\cdots (9)$$

Equation (9) is substituted into equation (8) and below result is obtained.

$$\text{Annual sand discharge } Q = 1{,}210 \sim 11{,}260 \ (m^3/\text{year}) \quad \cdots\cdots\cdots\cdots (10)$$

【Estimated from similar river : sand discharge from river in Anse La Raye】

Anse La Raye is just 18.5 km north of Choiseul in direct distance. Both are facing to the west Caribbean Sea, so the precipitation is considered to be similar.

The drainage area of the inflowing river in Anse La Raye is 5.24 km^3, which is almost the same as the Choiseul river (4.33 km^2).

In Anse La Raye, the sand discharged from the river is deposited on the front of river mouth. It is reported that 47,000 m^3 of sand has been deposited on the seabed by comparing the bathymetric data in 2006 and 2012[4)]. The beach topography of Anse La Raye is a pocket beach, and it can be understood that the sand discharged from the river is deposited almost on the seabed in front of river mouth. Then, the volume of sand discharge per year is 7,833 m^3/year.

Table 6-8 summarizes the above estimates. The average sand discharge from the Choiseul river is 5,800 m^3/year.

Table 6-8 Estimated annual runoff sand volume of the Choiseul River

Method	Annual sand discharge Q (m^3/year)
Empirical method 1	3,340
Empirical method 2	1,210～11,260
Estimated from similar river	7,833
Average	5,800

【Reference】

[6)] The Collection of Hydraulic Formulae (Japan Society of Civil Engineers 1999) p.151

[7)] Climate Change Knowledge Portal：
http://sdwebx.worldbank.org/climateportal/index.cfm?page=country_historical_climate&ThisRegion=Latin%20America&ThisCCode=LCA#（Latest viewing date ：June 26, 2018）

[8)] Digital Globe：https://discover.digitalglobe.com/（Latest viewing date：June 26, 2018）

[9)] JICA and ECOH: Follow-up Cooperation Study Report on the Project for Improvement of Fishery Infrastructure in Anse La Raye, Saint Lucia, March 2013.

(2) Sand supply from sea cliff (Aerial photograph analysis)

The amount of yearly sand supply from the sea cliff located on the south side of the Choiseul fishing port can be roughly estimated by the height of the sea cliff and its recession rate.

The sea cliff recession speed is investigated by analyzing Photo 6-59. Although all data of these aerial photographs are electronic data, their resolution is not necessarily sufficient for this analysis, so errors may somewhat occur in reading the location of sea cliff.

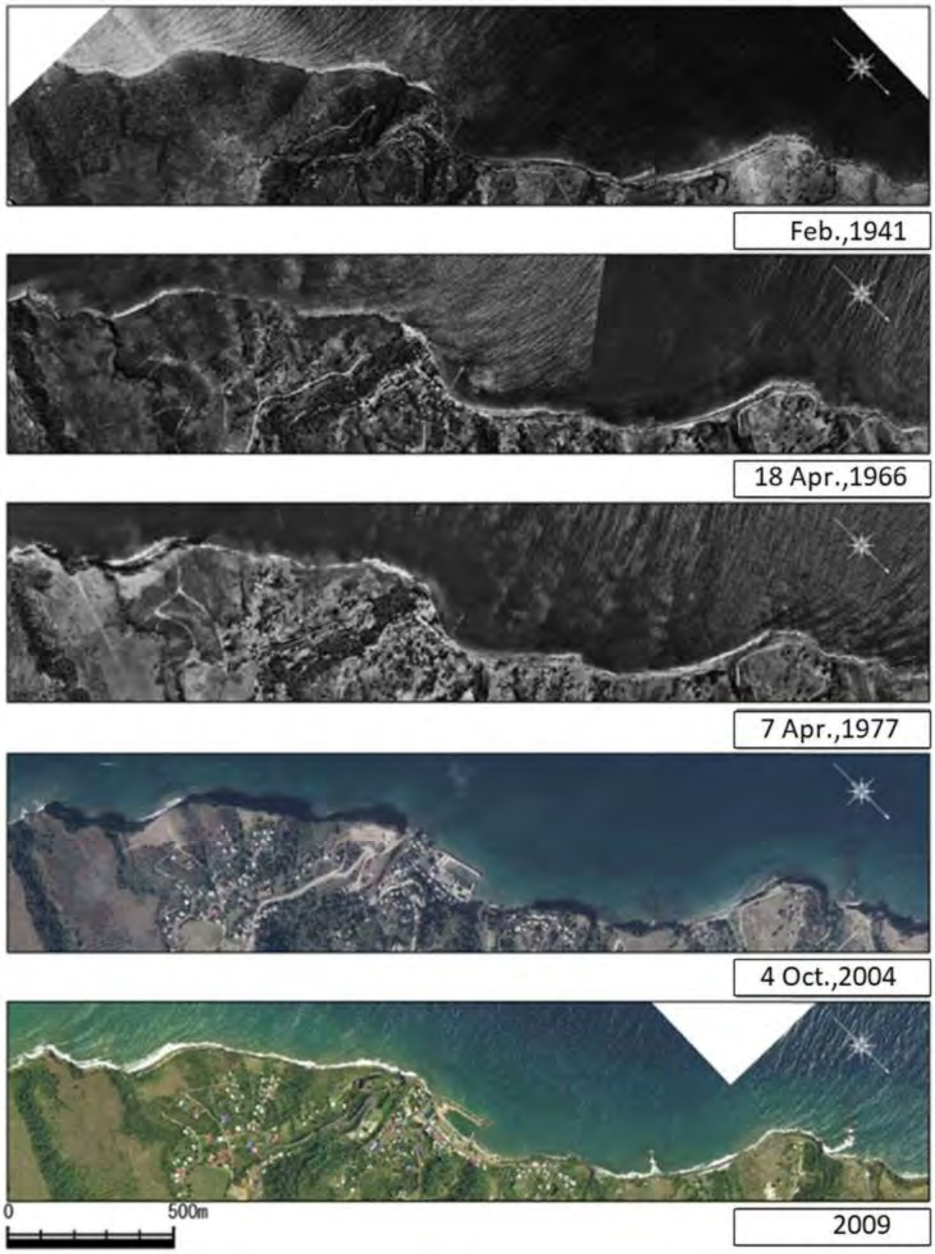


Photo 6-59 Aerial photographs used for analysis (From 1941 to 2009)

From these aerial photographs, positions of sea cliff are read on the survey lines with the interval of 10 m in the longshore direction.

Figure 6-40 shows the positions of the sea cliff in each year based on the positions of the sea cliff in 1941. In this figure, the negative value is the sea cliff recession amount. Macroscopically, the red bar gets longer with the years, which is recession of sea cliff. In detail, the data in 1966 and 1977 have some forwarding points. This is interpreted as a reading error because the sea cliff can never move forward.

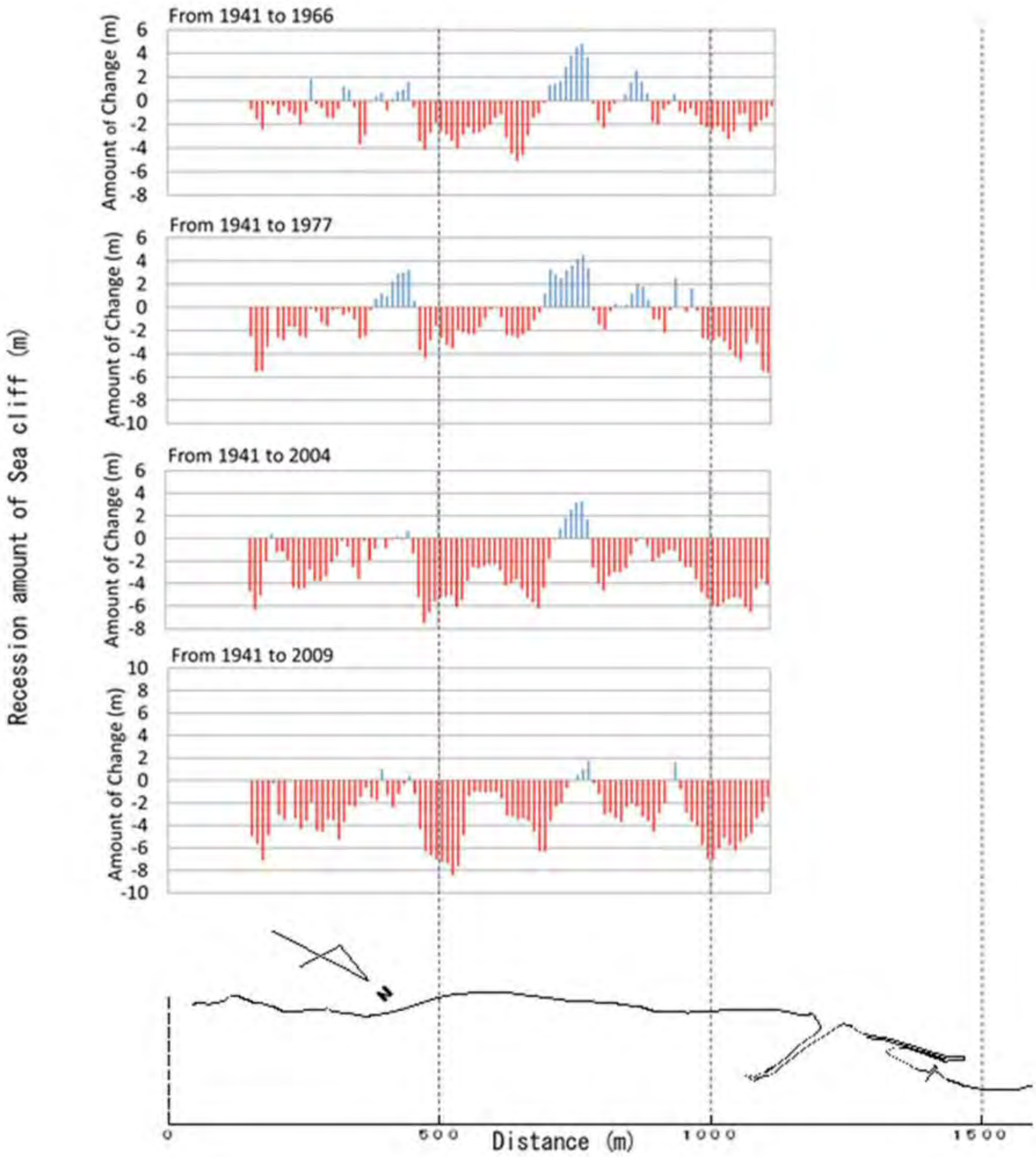


Figure 6-40 Longshore distribution of recession amount of sea cliff
(base year: 1941)

Figure 6-41 shows the frequency distribution of the recession distance of the sea cliff for 68 years from 1941 to 2009. The mean value is 3.16 m. The average speed of recession is as follows.

Average recession speed of sea cliff＝0.05m/year･････････････････(11)

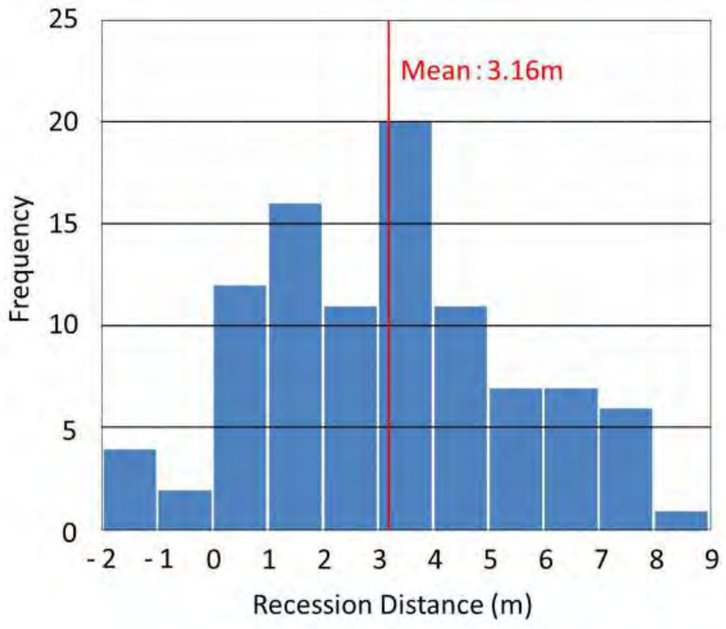


Figure 6-41 Frequency distribution of sea cliff recession distance from 1941 to 2009

The volume of sand supplied to the sea with recession of the sea cliff can be calculated by the multiplication of the recession amount of sea cliff and the height of the cliff (equation (12)).

$$\text{Sand supply from the sea cliff} \quad = \sum_{i=1}^{n} \Delta S_i \cdot h_i \cdot \Delta x \quad \cdots\cdots\cdots\cdots (12)$$

Where, i : survey line number

ΔS_i : the amount of cliff recession (m)

h_i : height of the cliff (m)

Δx : Longshore interval of survey line (=10 m)

The elevation of the top of the sea cliff on the same survey lines with the interval of 10 m in the longshore direction has been read from a photograph of Google Earth, photographed on March 24, 2018. The upper part of Figure 6-42 is the reading point of the sea cliff elevation, and the lower part is the result.

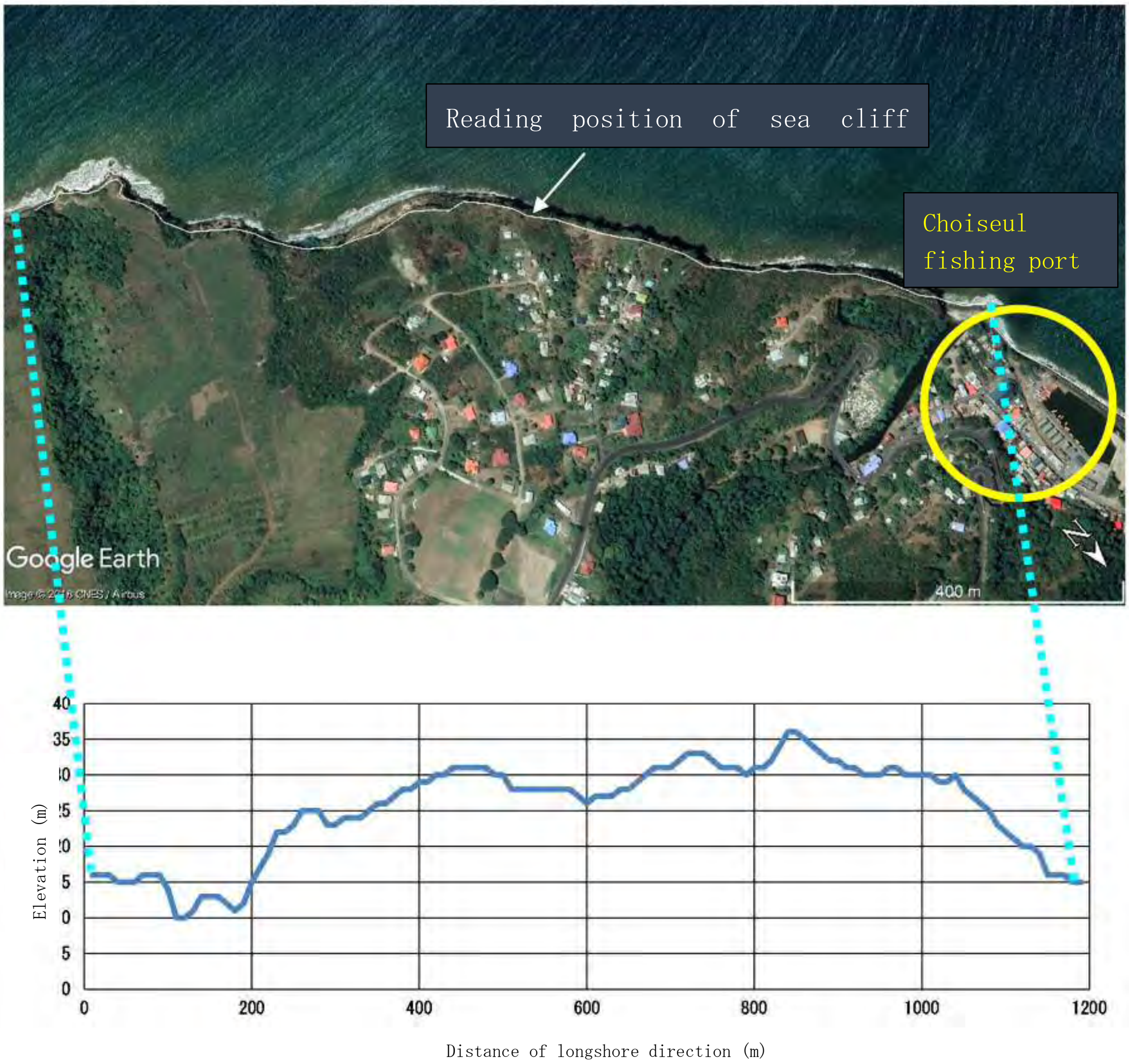


Figure 6-42 Reading position of cliff topography (upper figure) and its elevation (lower figure)

Figure 6-43 shows the amount of sand supply calculated from recession speed and the height of the sea cliff, based on 1941. The annual average supply is slightly different depending on the target period as shown in Table 6-9. Since the resolution of aerial photographs taken in 1941 is a bit inferior, these averages are calculated.

Table 6-9 Annual sand supply from the sea cliff

Term	Sand supply（m^3／year）
From 1941 to 2009	1,238
From 1966 to 2009	1,524
Average	1,380

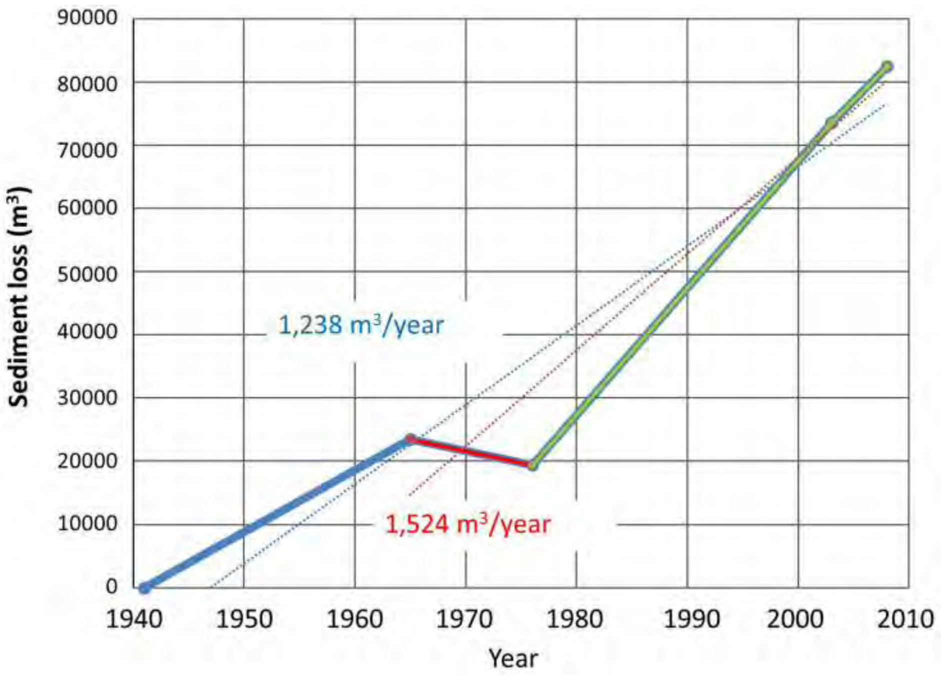


Figure 6-43 Accumulation of sand supplied from the sea cliff

The above results are shown in Table 6-10. The ratio of sand supply is; river: sea cliff = 4.2: 1, so the supply from river is 4.2 times. In addition, the total sand supply volume is 7,180 m^3/year, and this volume is transported to the north direction or toward the Choiseul fishing port. The results of the study here (7,180 m^3/year) almost correspond with the longshore sand transport rate in front of the Choiseul fishing port as shown in Figure 6-24; 6,000 to 10,000 m^3/year of which basis is unclear in 6.4.1.

Table 6-10 Sand supplied from river and sea cliff

	From river	From sea cliff
Sand supply（m^3／year）	5,800	1,380
Contribution ratio	4.2	1
River + Sea cliff (m^3/year)	7,180	

6.7.2 Examination by fluorescent X-ray analysis

(1) Sand sampling points and X-ray fluorescence analysis

Sand samples used for X-ray fluorescence mineral analysis have been collected from November 14 to 18, 2017, at 4 points shown in Figure 6-44. Since, at the river upstream, two samples have been collected from the riverbed and side slope, the number of samples is 5 in total. Elemental analysis by X-ray fluorescence analysis has been performed by the SQX method.

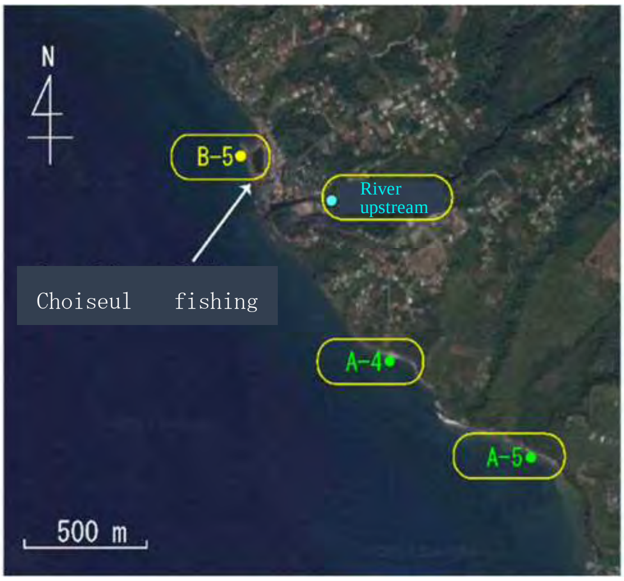


Figure 6-44 Sand sampling points

(2) Estimation of contribution ratio

The top 4 types of metal oxides; SiO_2, Fe_2O_3, Al_2O_3 and CaO, with high content in the samples collected at B-5, front beach in the west breakwater of the Choiseul fishing port, are analysis targets. Regarding two samples from the river and the sea cliff respectively, average values of two samples are used for estimation.

Figure 6-45 shows the content rates of 4 metal oxides at each sampling point. The content rates are listed in 3 rows in Table 6-11; sea cliff sample a_i, fishing port sample b_i, river sample c_i.

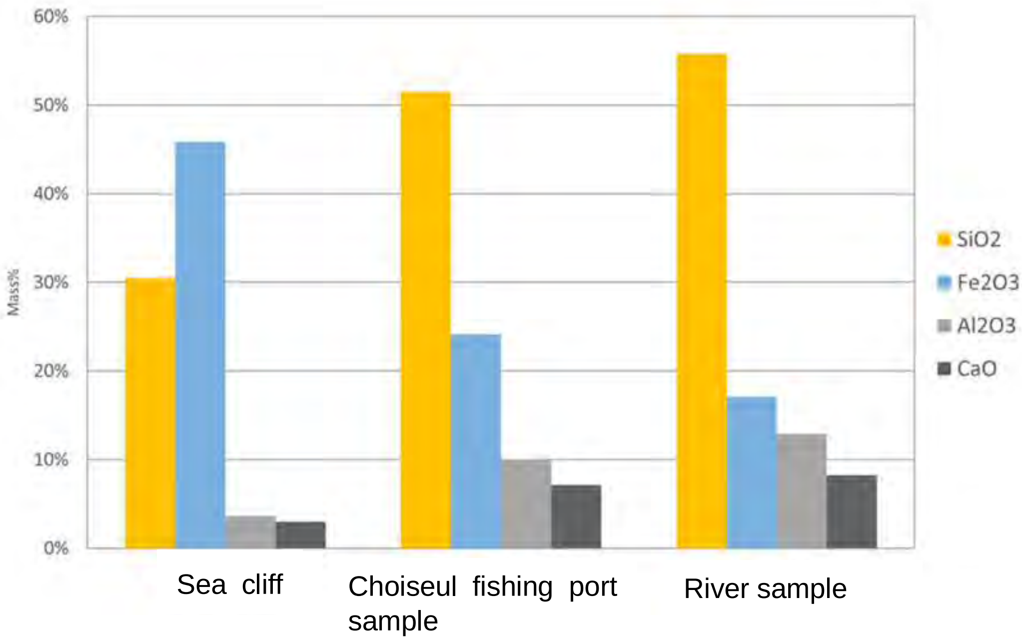


Figure 6-45 Content rates of major metal oxides in sea cliff sample, river sample and fishing port sample

Table 6-11 Contribution ratios of deposition between sand provided by the sea cliff and river

i	1	2	3	4	
Name of metal oxide	SiO_2	Fe_2O_3	Al_2O_3	CaO	Sum of content rates
Sea cliff samples a_i	30.5	45.9	3.6	3.0	83.0
Fishing port sample b_i	51.5	24.1	9.9	7.2	92.7
River samples c_i	55.8	17.1	12.9	8.2	94.0
$b_i - a_i$	21.0	-21.8	6.3	4.2	
$c_i - b_i$	4.3	-7.0	3.0	1.0	
$(Y/X)_i$	4.9	3.1	2.1	4.2	

Regarding the data listed in Figure 6-45, or data in the three rows in Table 6-11, the ratio of sea cliff origin sand and river origin sand to the deposition of the Choiseul fishing port is examined. For the examination, several parameters are defined as follows.

a_i : Content of metal oxides (i) in sea cliff sample (mass %)
b_i : Content of metal oxides (i) in the sample of Choiseul fishing port (mass %)
c_i : Content of metal oxides (i) in river sample (mass %)

Assuming that sand X ("kg") supplied from the sea cliff and sand Y ("kg") supplied from river are mixed and sand $(X+Y)$ ("kg") is deposited in the Choiseul fishing port, following equation is established.

$$\frac{a_i}{100}\cdot X + \frac{c_i}{100}\cdot Y = \frac{b_i}{100}\cdot (X+Y) \qquad \cdots\cdots\cdots\cdot(13)$$

Therefore,

$$(Y/X)_i = \frac{b_i - a_i}{c_i - b_i} \qquad \cdots\cdots\cdots\cdots\cdots\cdots\cdot(14)$$

The value of the parameter $(Y/X)_i$ means the ratio (contribution ratio) of the river supply when the sea cliff supply is set as 1. The contribution ratio of rivers shown in the bottom row of Table-11 is in the range of $(Y/X)_i$= 2.1 to 4.9, although it varies slightly depending on the metal oxide. That is, the analysis results of the content rates of any metal oxides also have a large contribution ratio of the river. If the average value of the contribution ratio is evaluated as a weighted average considering the metal content of the sample taken in the port is follows.

$$\overline{\left(\frac{Y}{X}\right)} = \frac{\sum_{i=1}^{4} b_i \cdot (\frac{Y}{X})_i}{\sum_{i=1}^{4} b_i} = 4.1 \qquad \cdots\cdots\cdots\cdots\cdots\cdots\cdot(15)$$

Therefore, the river supply is on average about 4.1 times of the sea cliff supply.

Above Contribution ratio of river supply sand volume and sea cliff supply sand volume is

① Estimated by sand supply from the Choiseul river and the sea cliff; 4.2: 1
② Estimated based on X-ray fluorescence analysis; 4.1: 1

The sand supply from the river is more than 4 times of the supply from the sea cliff.

~~~ Appendix for Chapter 6: sand movement in bed load by oscillatory flow of waves (mechanism of net movement) ~~~

As shown in Figure 6-46, the situation in which a sine wave with period T propagates from right to left is considered. The flow direction at the bottom is the same as the wave propagation in the area where the water surface is raised above the average water surface (area from A to B). Conversely, in the area where the water surface is lower than the average water surface (area from B to C), the water flows in the direction opposite to the wave propagation. In the oscillatory flow of waves, the flow direction at a certain moment differs depending on the place.

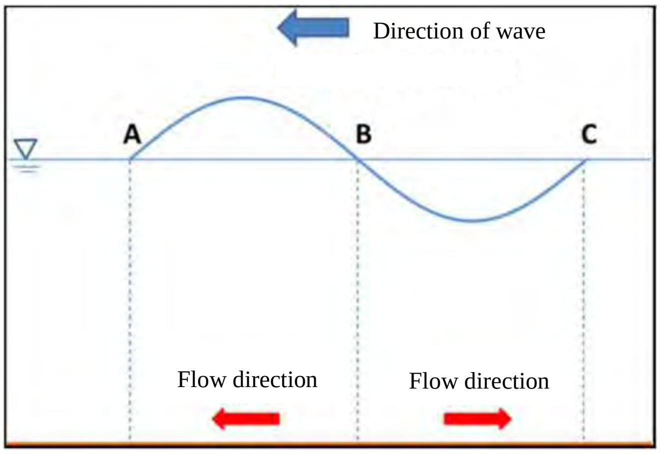


Figure 6-46 Relationship between propagating wave phase and bottom flow direction

Next, it is assumed that there is one particle of sand at the bottom D below the point A with respect to the sine wave ABC in Figure 6-47. The sine wave ABC propagates to A 'AB during a half period ($T/2$), which is drawn in a red broken line. During this time, since the part that the water level is higher than the average water surface passes the point D, the flow is always leftward and the sand particle is transported to the left point D'. Therefore, the water surface at the point D' is higher than the average water surface even after a half period ($\Delta\eta > 0$), so the flow continues to the left while the wave propagates for a while of δt. That is, the sand that is initially at the point D is transported leftward for a time ($T/2 + \delta t$) longer than a half period.

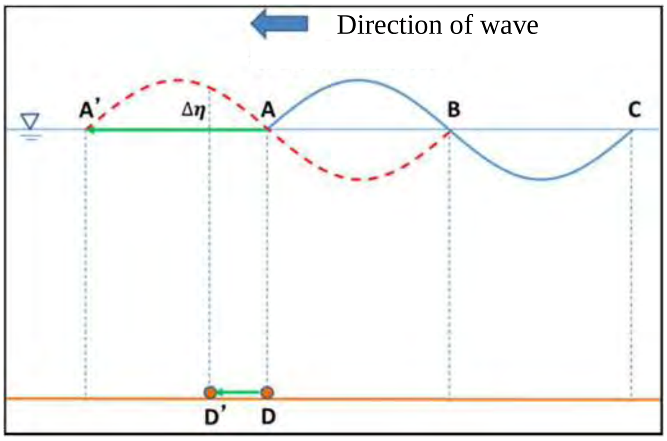


Figure 6-47 Sand particle transported in the same direction as the wave propagation

In Figure 6-48, a sine wave ABC in reverse phase to the previous one is now considered. When the wave propagates from the initial state, since the water level passing through the point D is always lower than the average water level during a half period, the flow direction at the point D is rightward. For this reason, the sand particle at the point D is transported to the right. When the sand particle is transported to the D 'point, although a half cycle time has not passed yet, the B phase (the phase with flow velocity of zero) propagation from the right is encountered. That is, the time during which the sand particle is subjected to the effects of the flow in the right direction, opposite to the wave propagation, is $T/2 - \delta t$.

To summarize the above explanation,
* Time duration that fluid force in the same direction as wave propagation effects on the sand:

$$T/2 + \delta t$$

* Time duration that fluid force in reverse direction of wave propagation effects on the sand:

$$T/2 - \delta t$$

In this way, since the time taken to be transported in the direction of wave propagation is long, sand particle is transported little by little in the same direction as the wave propagation for each wave passing.

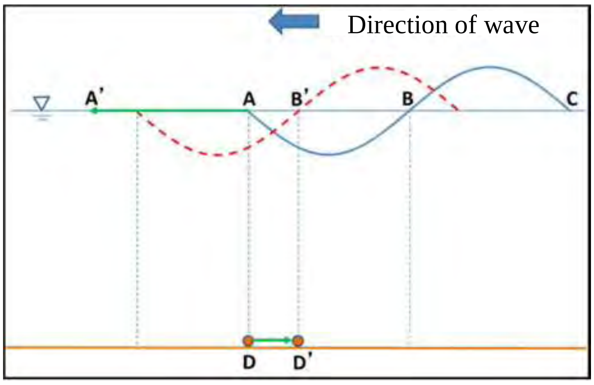


Figure 6-48 Sand particle transported in the direction opposite to the wave propagation

Figure 6-49 is a schematic drawing of the path of sand particle being transported from the port entrance to the interior of the port in bed load, taking time on the longitudinal axis. Sand moves back and forth by every wave and is transported to the same direction as the wave propagation with an average speed shown by a red dashed arrow. Even if the net transport of sand in the direction of wave propagation during one cycle of the wave is, for example, 0.1 mm, sand is transported to the interior of the port about 1.7 m in a day because the daily number of the waves with its period of 5 seconds is approximately 17,000.

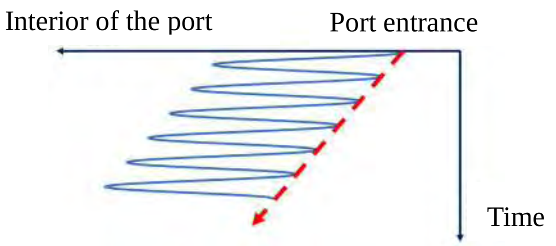


Figure 6-49 Schematic drawing for trajectory of sand movement from the entrance to the interior of the port

Chapter 7　Consideration on countermeasures against deposition

Chapter 7 Consideration on countermeasures against deposition

7.1 Design of countermeasures by numerical simulation

7.1.1 Routes of sand transport and basic policy for designing countermeasures

【Routes of sand transport】

Facilities such as the breakwater at the Choiseul fishing port had been completed by November 2002. After that, since the deposition begun to occur in the port, an additional breakwater has been constructed at the tip of the existing breakwater during April to July 2008.

Figure 7-1 is a schematic drawing of sand transport routes before construction of the additional breakwater, which cause the deposition in the port. The sands being transported northward along the breakwater fork into two routes. The one goes around the breakwater tip into the port (Route A), and another is further northward (Route B). The sand taking Route A, which causes deposition in the port, goes around the tip of the breakwater and intrudes into the port along the breakwater.

Figure 7-2 shows the routes of sand transport after construction of the additional breakwater. First, the sands being transported northward along the breakwater fork into two routes: one is Route A that goes around the inside of the port at the tip of the breakwater, and another is Route B. Then Route C is branched from Route B, carrying sand to the beach in the area protected by the additional breakwater, and accreting shoreline. After the shoreline accretes up to the tip of the groin, the sand from Route C is transported into the port. As a result, the sand is deposited behind the groin. There was only one route of sand inflow before construction of the additional breakwater, but after the construction, sand is carried into the port through two routes.

Furthermore, while the sand from Route A was transported to inside the port and deposited before the construction of the additional breakwater as shown in Figure 7-1, sand from Route A after construction it becomes more unlikely to be transported to interior of the port, and the amount seems to be smaller as shown in Figure 7-2.

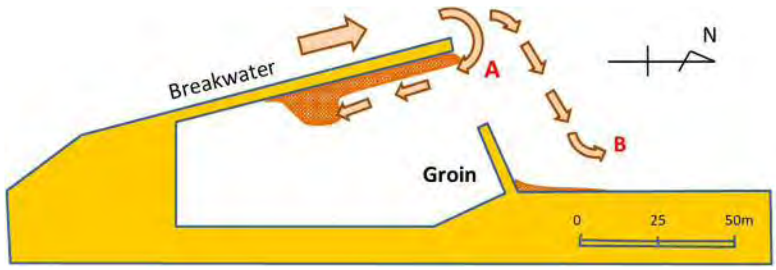


Figure 7-1 Schematic drawing of sand transportation routes before construction of additional breakwater

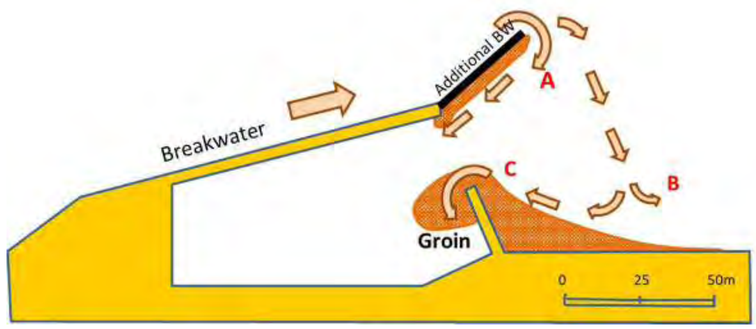


Figure 7-2 Schematic drawing of sand movement after construction of additional breakwater

Under the present situation with the additional breakwater, there exists two routes transporting sand to the fishing port (Figure 7-2):

- Route 1: A route going around the tip of the groin (Figure 7-2; Route C),
- Route 2: A route going around the tip of the breakwater (Figure 7-2; Route A).

The basic policy for considering countermeasures in the Choiseul fishing port is the way of managing these routes.

In Photo 7-1, Route 1 is clearly identified. The sand movement is largely subject to the nearshore currents. Figure 7-3 shows the simulation results in case that the additional breakwater exists. For the simulation, wave height of 0.3 m, wave period of 7.0 s, and wave direction of S is respectively set as a wave condition. This condition is the most frequent one based on the wave hindcasting results for 17 years from 2002 to 2018. Wave spreading parameter, S_{max}, is assumed to be 75. The nearshore currents near the tip of the additional breakwater go to the north beach and diverges close to the shoreline. After that, the southward currents which go to the port entrance (circled with a red dashed line) is stronger than the ones going southward. The sand transport through Route 1 confirmed in Photo 7-1 is caused by the effects of these nearshore coastal currents.

Photo 7-1 An example where Route 1 is clearly identified on August 13, 2018

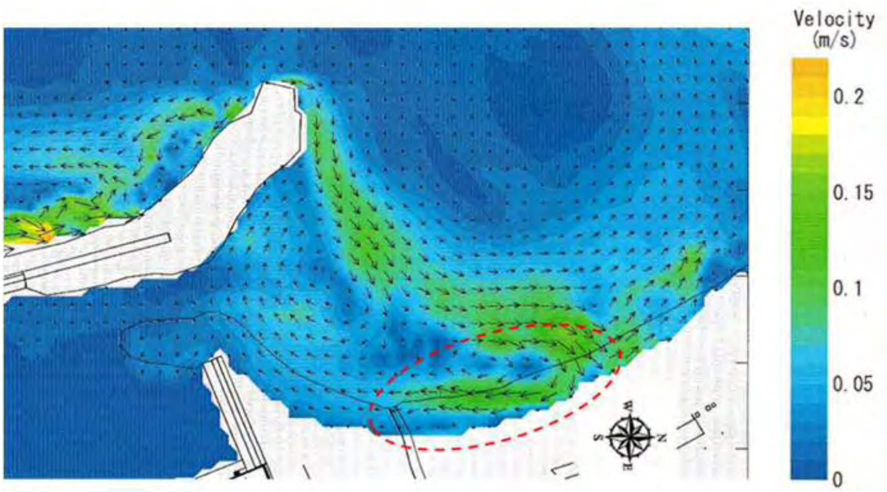


Figure 7-3 Nearshore currents with additional breakwater

【Blocking of Route 1, Figure 7-4】

Since Route 1 is a route of sand transport to the protected area behind the additional breakwater, basic idea of the countermeasure is to block the route. There are many examples of this kind of sand transport, therefore it has been already known that such sand can be controlled, in other word blocked by the groin constructed almost at right angles to the shoreline referring to the past experiences. The effects of the construction of the groin is examined by shoreline change numerical simulation named one-line model. In addition, a function of the groin preventing sand transport has its continuity (Refer to p.7-3 Commentary).

【Changing Route 2, Figure 7-4】

As for Route 2, it has been known that sand transport cannot be controlled (blocked) from the experiences of construction of the additional breakwater in 2008. In other words, even if the sand transport northward along the breakwater is blocked by the additional breakwater, the trapped sand finally reaches full of the trapping capacity of the additional breakwater and the function of blocking sand transport disappears.

Therefore, the basic policy is to change the route of sand transport, so that the sand currently intruding into the port is smoothly transported to the northern coast, instead of blocking such sand.

In control of sand transport, blocking sand transport is a general one. However, countermeasures making the sand smoothly pass by are seldom considered so far, so only a few experiences and technology have been gained. Thus, experiments or the like are necessary to carefully study and consider the details of the countermeasure.

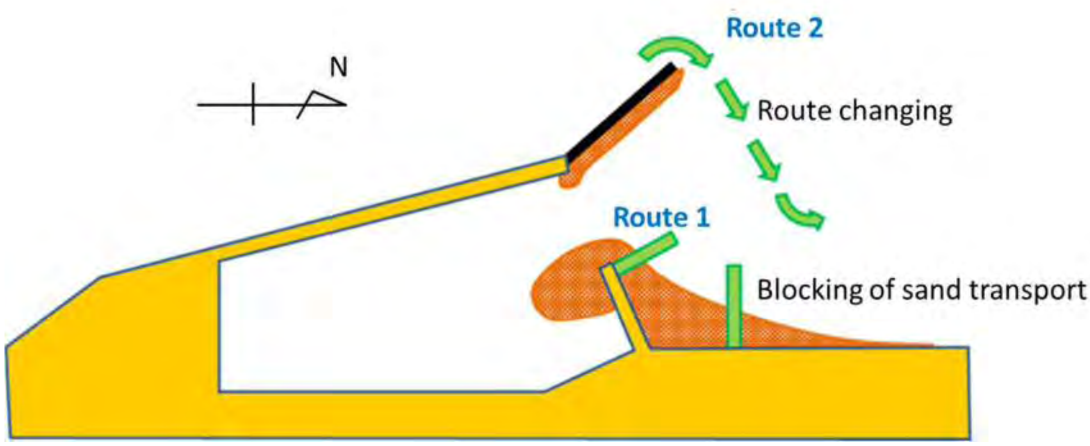


Figure 7-4 Basic policy for countermeasure managing Route 1 and 2

【Commentary: Continuity of the function of blocking sand transport by groin】

When a detached breakwater is constructed at offshore, the sandy beach behind forms a convex equilibrium topography such as salient or tombolo as shown in Figure 7-5. Since the equilibrium topography is considerably stable, the shape of salient returns to the equilibrium position in a short term if the topography is temporarily changed by an artificial way.

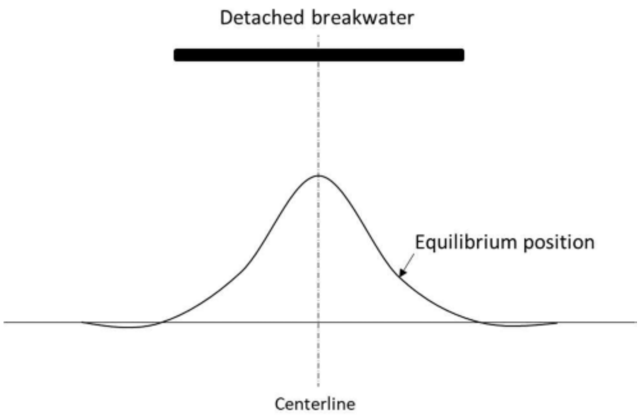


Figure 7-5 Topography of salient in equilibrium position

For example, when sand is artificially nourished near the tip of the salient in equilibrium position as shown in Figure 7-6, the shoreline (red dotted line) protrudes from the equilibrium position. Then, the nourished sand is carried toward both sides, the direction indicated by arrows in the figure, and the shoreline recesses to the equilibrium position (solid line). Conversely, when sand is removed from near the tip of the salient in equilibrium position as shown in Figure 7-7, the shoreline (green dotted line) recesses from the equilibrium position. Then, sand is carried from both sides toward the tip of the cuspate spit, the shoreline accretes to the equilibrium position (solid line), and the beach is recovered.

The equilibrium shoreline is considerably stable. Such shoreline is characterized by the recovery to the equilibrium position even if any disturbance changes its topography. In other words, shoreline in equilibrium position has a self-maintenance mechanism.

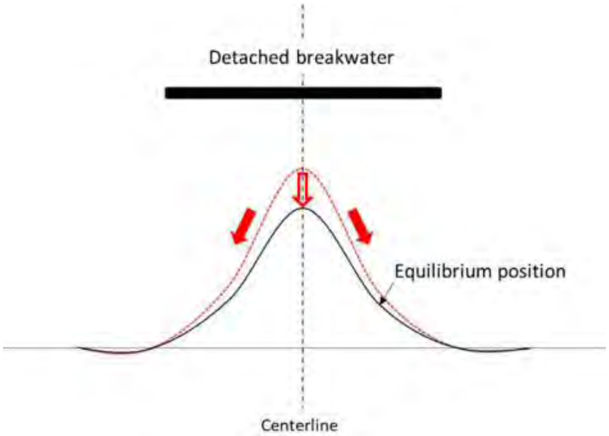


Figure 7-6 Nourished near the tip of salient

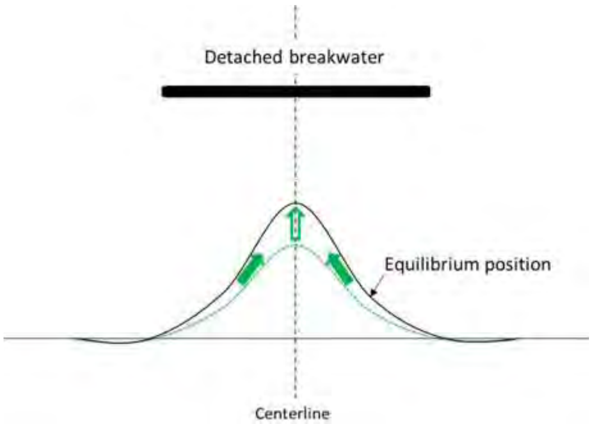


Figure 7-7 Removed near the tip of salient

Based on Figure 7-5, Figure 7-8 is drawn. Added structures are a long groin to prevent sand transport from left side and a L-shape groin on centerline. When such groins are constructed, sand is not deposited in the dashed line of the Tombolo topography, and only the shoreline on the right side of the L-shaped groin is formed. As time passes, the shoreline is in equilibrium position. The equilibrium shoreline is considerably stable having a self-maintenance mechanism, therefore if any sand is deposited there, such sand is shortly transported rightward.

Therefore, “The facility colored in red (hereinafter referred to as “wing jetty”) at the tip of the L-shaped groin is constructed not only to prevent sand from entering into the port, but to form shoreline in equilibrium position on the right side, which blocks the sand to be transported leftwards.”

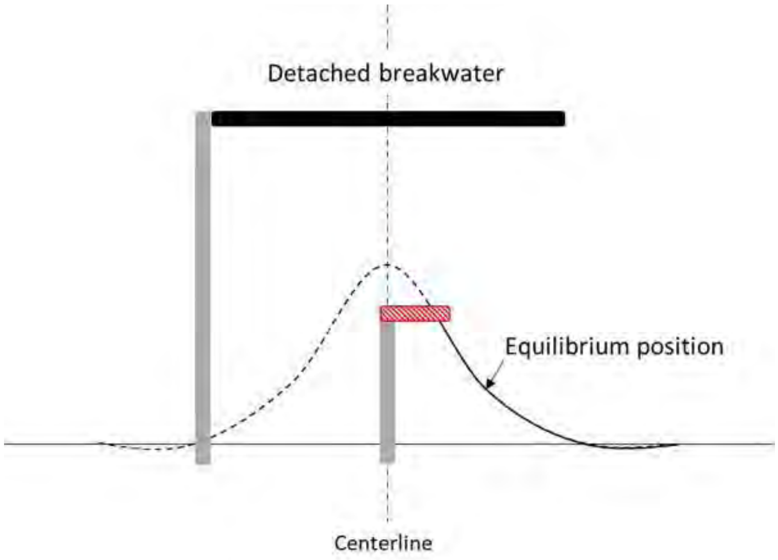


Figure 7-8 The function of wing jetty, colored in red

7.1.2 Study for blocking Route 1

－ numerical simulation model for shoreline change prediction(One-line Model）－

Since Route 1 is a route of longshore sand transport to the protected area behind the additional breakwater, shoreline change can be simulated by a one-line model incorporating the longshore sand transport rate formula. However, applicability of the model is subject to the reproducibility of the actual past shoreline, changes occurred around the Choiseul fishing port. If the reproducibility is confirmed, this model can be applied for future prediction of shoreline changes.

(1) Specifications used in numerical simulation for shoreline change prediction

[Longshore sand transport rate formula]

Equation (1) by Ozasa and Brampton (1979), which can reproduce sand transport to the protected area, is used.

$$Q = K_1 \frac{1}{(\rho_s - \rho) g (1-\gamma)} \left(E \cdot C_g\right)_b \left(\sin\theta_b - \frac{K_2}{K_1}\frac{\partial H_b}{\partial y}\cot\beta\right)\cos\theta_b, \quad \cdots\cdots\cdots\cdots(1)$$

where, Q is longshore sand transport rate, K_1 and K_2 are dimensionless sand transport rate coefficients, ρ_s is sand density, ρ is water density, g is gravitational acceleration, γ is sand porosity, E is wave energy density, C_g is wave group velocity, θ is wave direction, H is wave height, $\tan\beta$ is seabed slope, Suffix b means wave breaking point.

[Wave specifications]

Waves at offshore of the Choiseul fishing port; significant wave height, period and wave direction, are extracted from the results of wave hindcast at 20-minute intervals for 18 years from 2000 to 2017. Specifications of the energy-averaged wave; mean wave height, mean wave period and mean wave direction, are calculated by the following equations for three representative wave directions.

Mean wave height $$\tilde{H} = \sqrt{\frac{\sum_{i=1}^{N}(H_i{}^2 \cdot T_i)}{\sum_{i=1}^{N} T_i}} \quad \cdots\cdots\cdots\cdots(2)$$

Mean wave period $$\tilde{T} = \frac{\sum_{i=1}^{N} T_i}{N} \quad \cdots\cdots\cdots\cdots(3)$$

Mean wave direction $$\tilde{\theta} = \frac{\sum_{i=1}^{N}(\theta_i \cdot H_i{}^2 \cdot T_i)}{\sum_{i=1}^{N}(H_i{}^2 \cdot T_i)} \quad \cdots\cdots\cdots\cdots(4)$$

Three representative wave directions are W to SSW, S, and SSE to E (see Figure 7-9). Table 7-1 shows the specifications to be used in the numerical simulation for shoreline change, and the calculations take the number of monthly effected days into consideration.

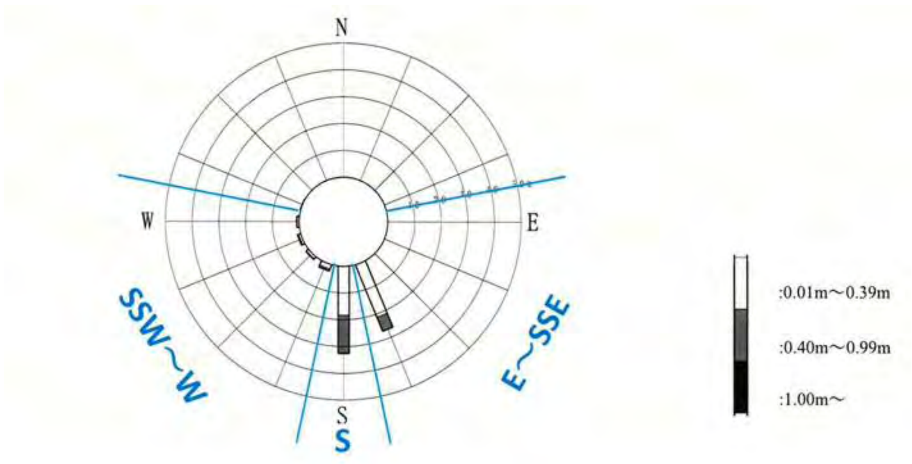


Figure 7-9 Frequency for wave direction and three representative waves

Table 7-1 Energy-averaged wave specifications of three representative wave directions

Representative wave direction	Mean wave direction ($\tilde{\theta}$)	Mean wave height ($\tilde{H}$)	Mean wave period ($\tilde{T}$)	Effected days
W～SSW	N227.6°E	0.35m	9.2s	34.3
S	N177.7°E	0.36m	7.8s	180.0
SSE～E	N164.1°E	0.31m	5.9s	150.7

[Tide]

M.S.L.＝C.D.L＋0.23m

[Seabed slope]

Based on the seabed topography on the coast near the fishing port (Figure 7-10), the average seabed slope is set as 1/30.

[Depth of closure]

Referring to the cross-sectional drawings on the north side of the fishing port (Figure 7-11), the depth of closure, D, is set as 2.5 m (1.5 m above the mean sea level, 1.0 m underwater).

[Dimensionless sand transport rate coefficients, K_1 and K_2]

According to trial calculations, K_1 =0.10 and $K_2 = 0.81 \cdot K_1$ are obtained respectively.

[Boundary conditions for sand transport]

Based on the sand budget around Choiseul fishing port (see Figure 7-12), the amount of sand transport to the north of the Choiseul fishing port along the breakwater is 8,000 m^3/year. The boundary condition on the north is set so that sand comes and goes freely since the northern boundary is composed of natural beach. Other detail boundary conditions are described in each reproduction simulation case.

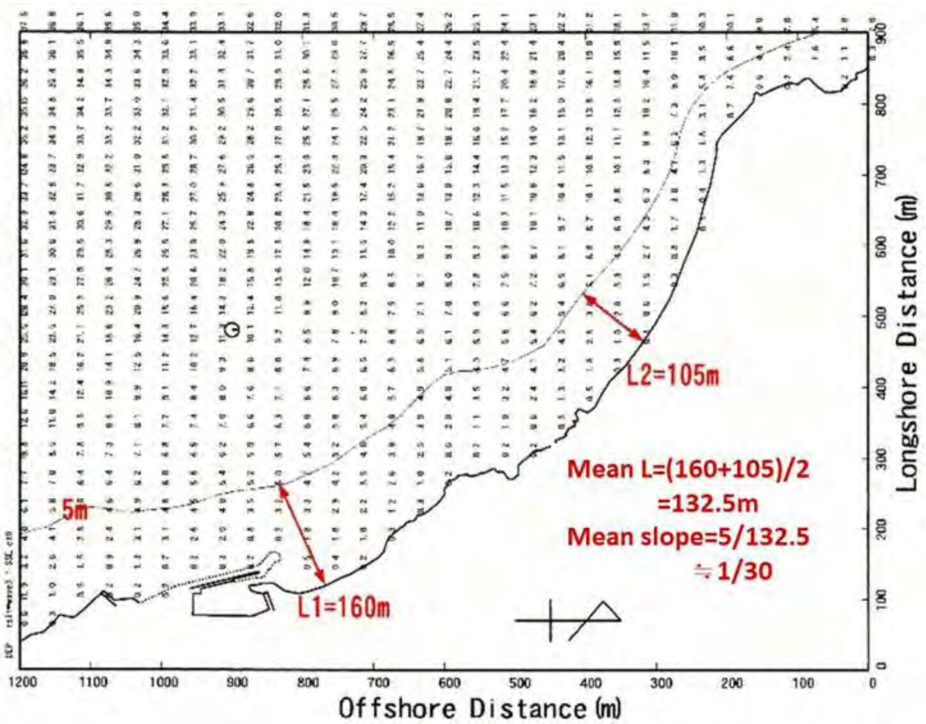


Figure 7-10 Seabed slope around Choiseul fishing port

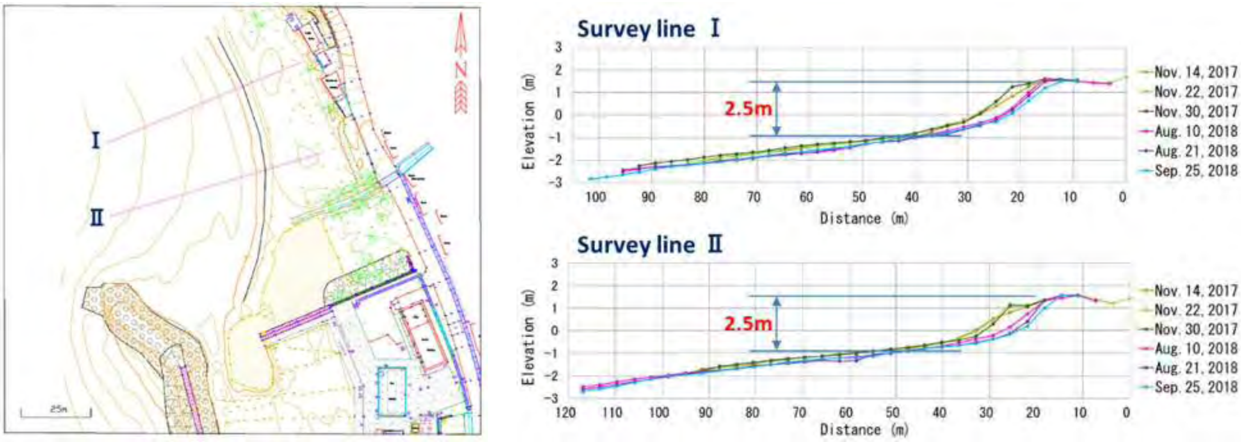


Figure 7-11 Beach profiles at north beach of the port

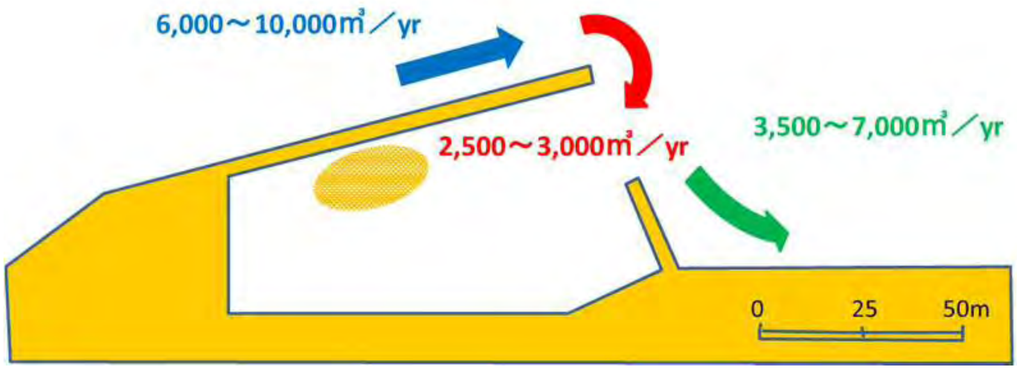


Figure 7-12 Sand budget around Choiseul fishing port (repost of Figure 6-24)

(2) Period of reproduction of shoreline changes

Figure 7-13 quite simply shows the record of construction in the Choiseul fishing port. Main facilities such as the breakwater have been constructed in 2002. The deposition in the port was identified just before the completion, and the additional breakwater has been constructed in 2008 as a countermeasure. After the construction of the additional breakwater, the deposition has been further accelerated, and the port entrance was completely closed as shown in the picture taken in November 2015. Since the end of December 2016, dredging (excavating) works by backhoe at the port entrance has been conducted so far. Artificial activities were made to the nature in the three terms colored in pink shown in Figure 7-13. When artificial activity is made, a corresponding change in the shoreline occurs. Therefore, the past shoreline changes of the following three stages are to be reproduced by the numerical simulation:

Stage 1: term when the effects by the construction of the Choiseul fishing port occurred (July 2002 to February 2007),

Stage 2: term when effects by the construction of the additional breakwater occurred (November 2009 to January 2018),

Stage 3: term during dredging work by backhoe is carried out (January 2018 to August 2018).

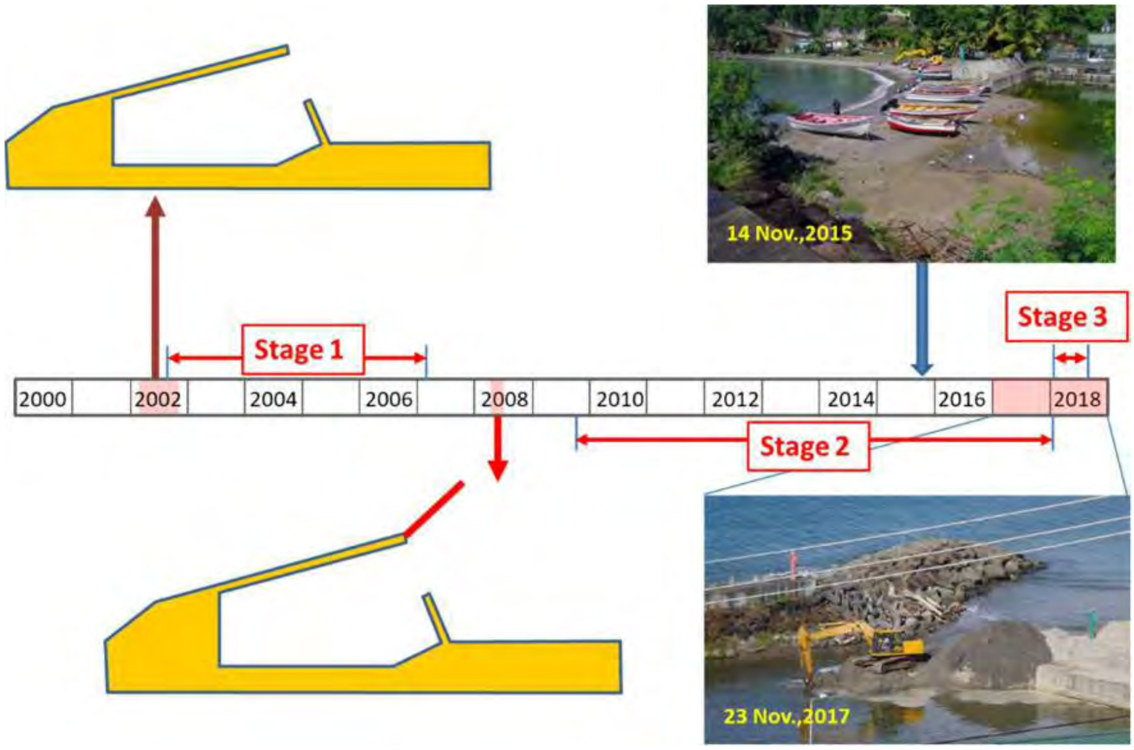


Figure 7-13 The history of construction in Choiseul fishing port and target stages for reproduction of simulation

(3) Reproduction of shoreline change in Stage 1

In Stage 1, effects of the construction of the Choiseul fishing port occur, and the period of shoreline change reproduction covers from July 2002 to February 2007. It is confirmed that the construction of the breakwater and the installation of wave-dissipating blocks have been completed at the end of November 2007. However, since the data indicating the construction progress of the breakwater is not available, it is assumed for the reproduction that facilities had been already completed to a certain extent that affected sand transport as of July 2002, and this timing is set as an initial condition of the reproduction. Since there is no shoreline data in July 2002, the shoreline before the construction of the Choiseul fishing port is assumed to be stable. Shoreline shown in the aerial photograph as of April 7, 1977 (Photo 7-2) is set as initial shoreline for reproduction.

Photo 7-3 was taken on February 11, 2007, and this shoreline is the reproduction target in Stage 1.

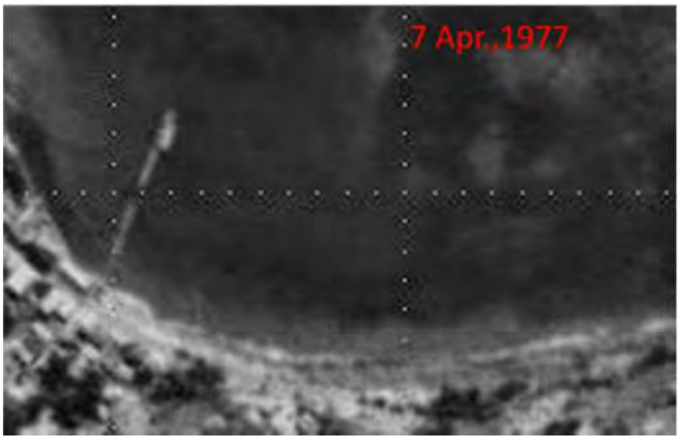


Photo 7-2 Initial shoreline at stage 1 (Taken on April 7, 1977)

Photo 7-3 Reproduction target in Stage 1 and also initial shoreline in Stage 2
(February 11, 2007, Google Earth)

As shown in Figure 7-12, the sand budget in Stage 1 is estimated in certain ranges. Each average value, shown in Figure 7-14, is applied in the reproduction. Sand intrudes into the port at a rate of 2,750 m^3/year, while sand of an average amount of 2,764 m^3/year is dredged by backhoe in the port (see Figure 7-15 and Photo 7-4). Therefore, the amount of sand transport that affects the shoreline change at north beach of the fishing port is 5,250 m^3/year.

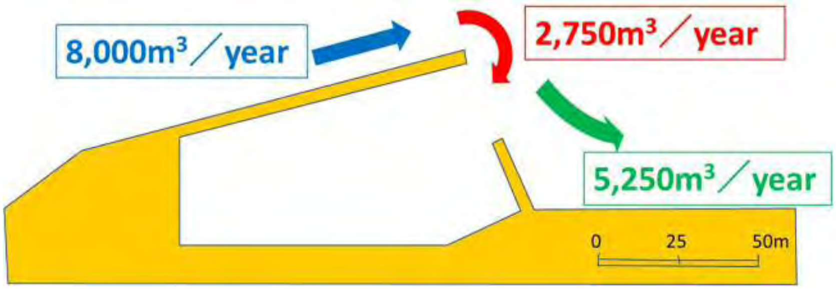


Figure 7-14 Sand budget considered in Stage 1

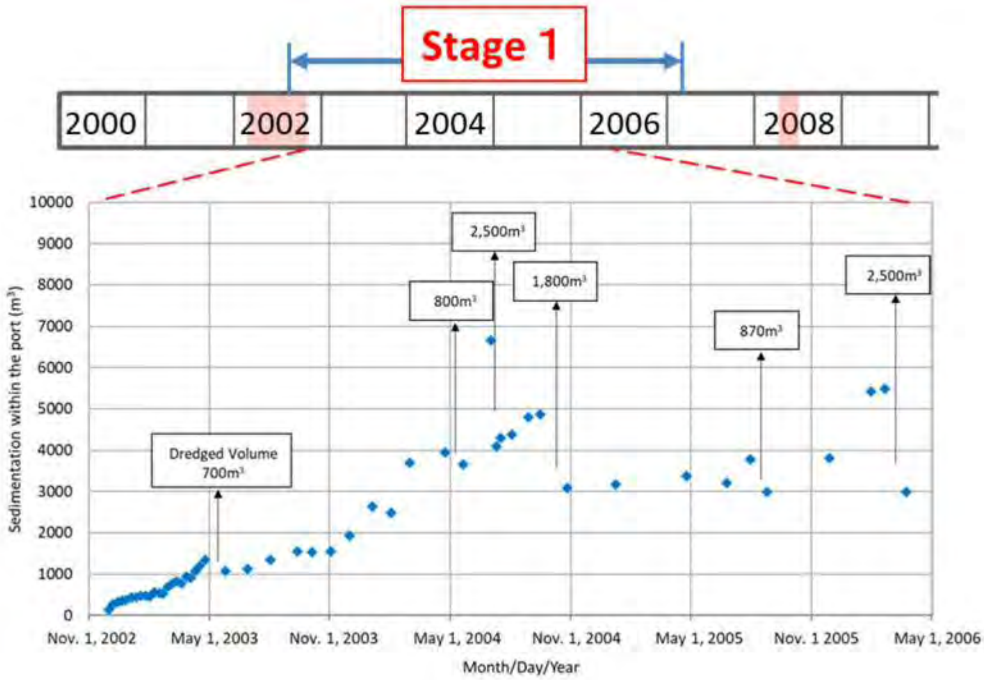


Figure 7-15 The amount of deposition and dredging in the port

Photo 7-4 Dredging work in the port during Stage 1 on September 21, 2004

Figure 7-16 shows the result of reproduction in Stage 1. The other results of reproduction are to be shown in the same format, and therefore explanation is given to read the figure at first. The upper figure is a plan view of the shoreline. The dotted line means the initial shoreline which is actually measured, and the red line is the simulated shoreline. Although it is easy to understand the change of shoreline in this figure, the reproducibility cannot be confirmed. Reproducibility can be confirmed in the lower figure. The figure shows the amount of change from the initial shoreline (measured value). The black dashed line is the amount of change in the actual measurement, and the red line is the amount of change obtained from the reproduction. The accreted and recessed areas are colored in red and blue respectively.

On the north beach, in the range of 300 m to 480 m along the coast, the shoreline accretes (colored in red), and the red line and the black dashed line are almost overlapped. In other words, the shoreline changes in Stage 1 can be reproduced by the one-line model.

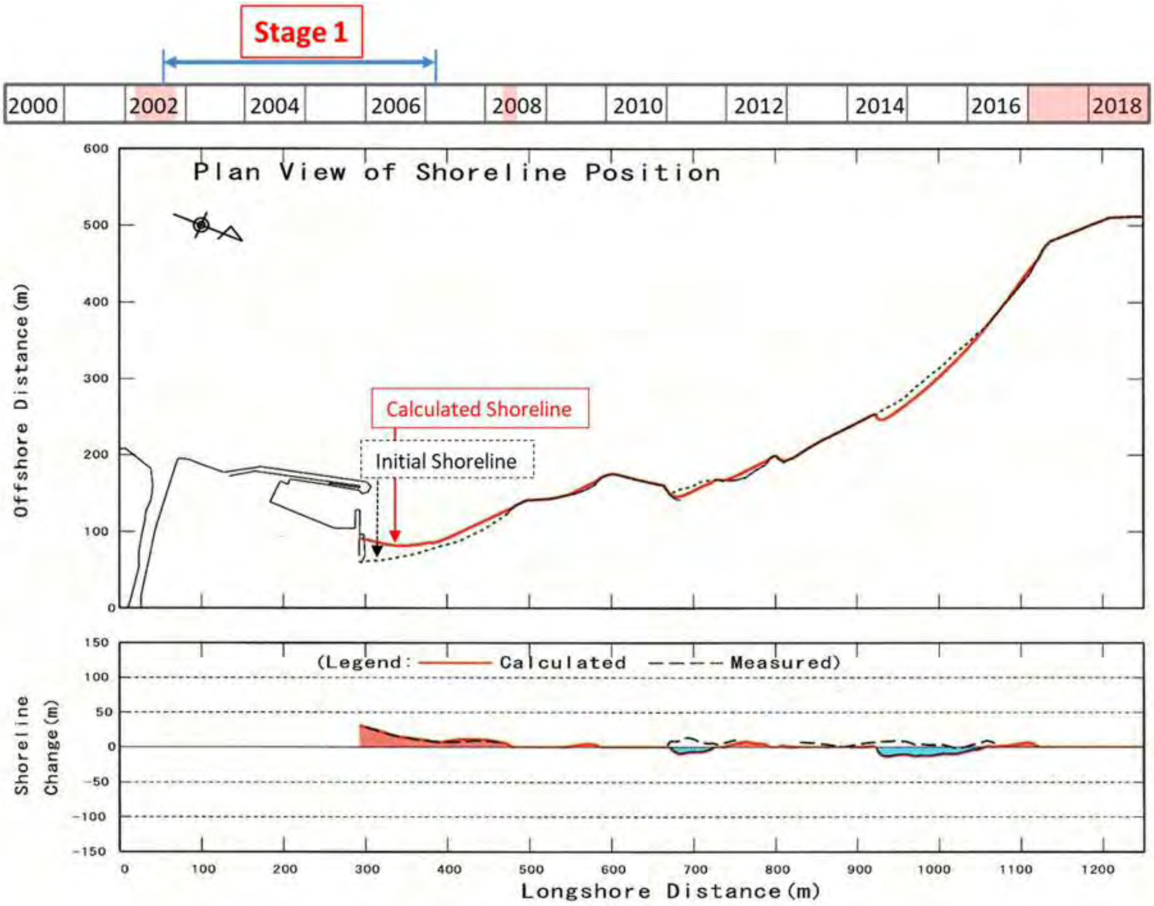


Figure 7-16 Results of reproduction simulation in Stage 1

(4) Reproduction of shoreline change in Stage 2

In Stage 2, an effect of the construction of the additional breakwater occurs on the shoreline. The period of reproduction covers from November 2009 to January 2018 (see Figure 7-17). The construction term of the additional breakwater was from April to July 2008. However, since there is no shoreline data at the time of completion, the shoreline as of November 2009 from Google Earth is used as the initial shoreline for reproduction as shown in Photo 7-5. On the other hand, the target shoreline of the reproduction is shown in Photo 7-6 on January 4, 2018.

According to Figure 7-17, at the end of the reproduction period, dredging work by backhoe was being carried out. However, dredging work in 2017 was conducted in minimum scale necessary to secure a waterway for fishing boats. Details are to be described later, in the section related to the reproduction period of Stage 3. Thus, the amount of dredged sand is judged as rather small, and is not taken into the reproduction.

According to Photo 7-5, as of the start of the reproduction period of Stage 2, the port entrance of the Choiseul fishing port was open. However, in the photo taken on November 14, 2015 (see Figure 7-16), the port entrance was completely closed. Therefore, the sand budgets during the periods of opened and closed port entrance are respectively set as shown in Figure 7-16. When the port entrance is opened, same as Stage 1, sand of 5,250 m^3/year out of 8,000 m^3/year is transported to the north beach. On the other hand, after the closure of the port entrance, the entire 8,000 m^3/year sand is transported to the north beach.

Since a timing of the port entrance closure is unknown, the trial simulations have been repeatedly conducted changing the closure timing to find the one that reproduced the target shoreline the best. As a result, the port entrance is assumed to be opened until August 2015 and closed from September 2015.

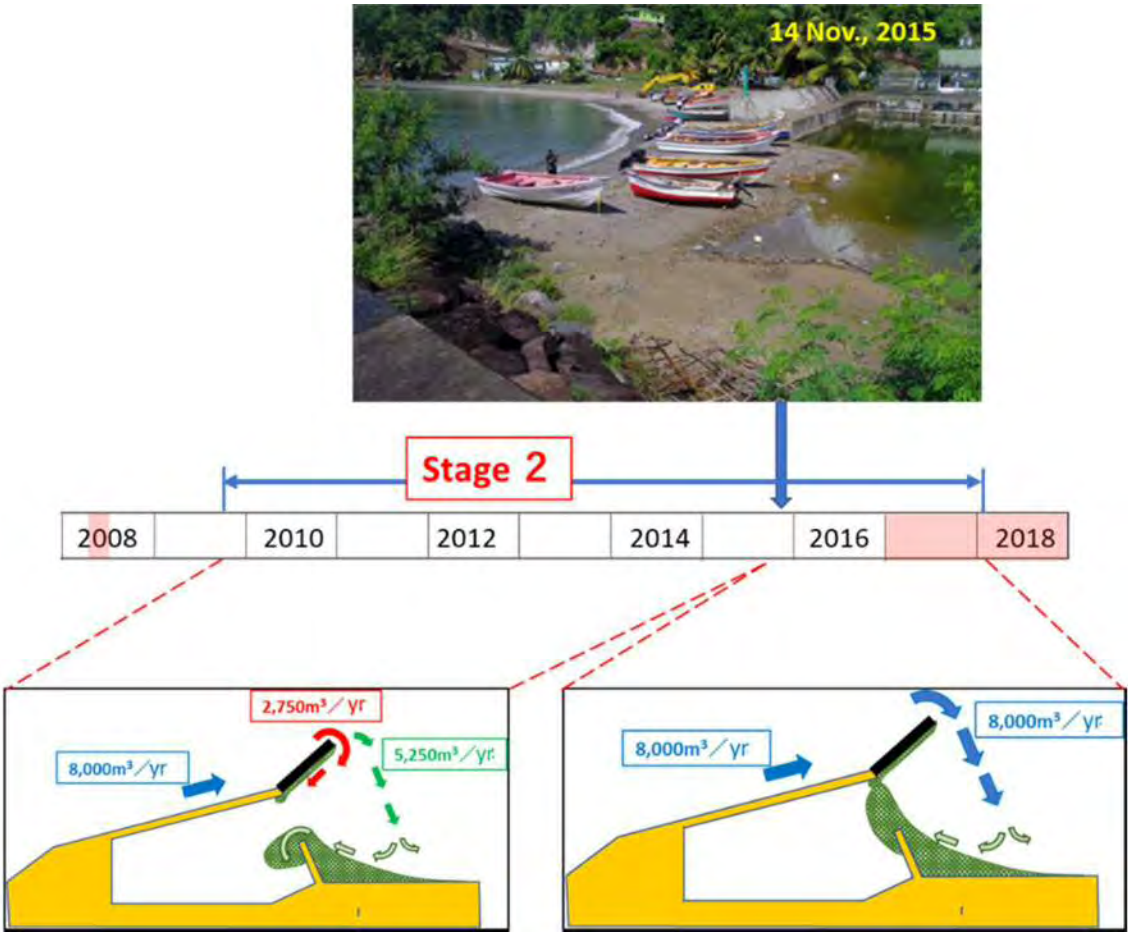


Figure 7-17 Sand budget in Stage 2

Photo 7-5 Initial shoreline in Stage 2 (November 23, 2009, Google Earth)

Photo 7-6 Target shoreline in Stage 2（January 4, 20108 , Google Earth）

Figure 7-18 shows the results of the reproduction in Stage 2 form November 2009 to January 2018. The upper figure is a plane view of the initial shoreline (black dotted line; actually measured) and the reproduction result (red line) of January 2018. The bottom figure shows the measured and simulated shoreline referring to the initial shoreline. The measured and simulated shorelines on north beach, 300 m to 450 m along the coast, are closely overlapped. Furthermore, in Figure 7-18, shoreline change in progress as well is shown in the middle. The middle figure compares the actual measured shoreline (black dashed line) on September 27, 2015 with the simulated shoreline (red line) referring to the initial shoreline. The high reproducibility of the shorelines including the target shoreline and shoreline in progress of simulation are confirmed.

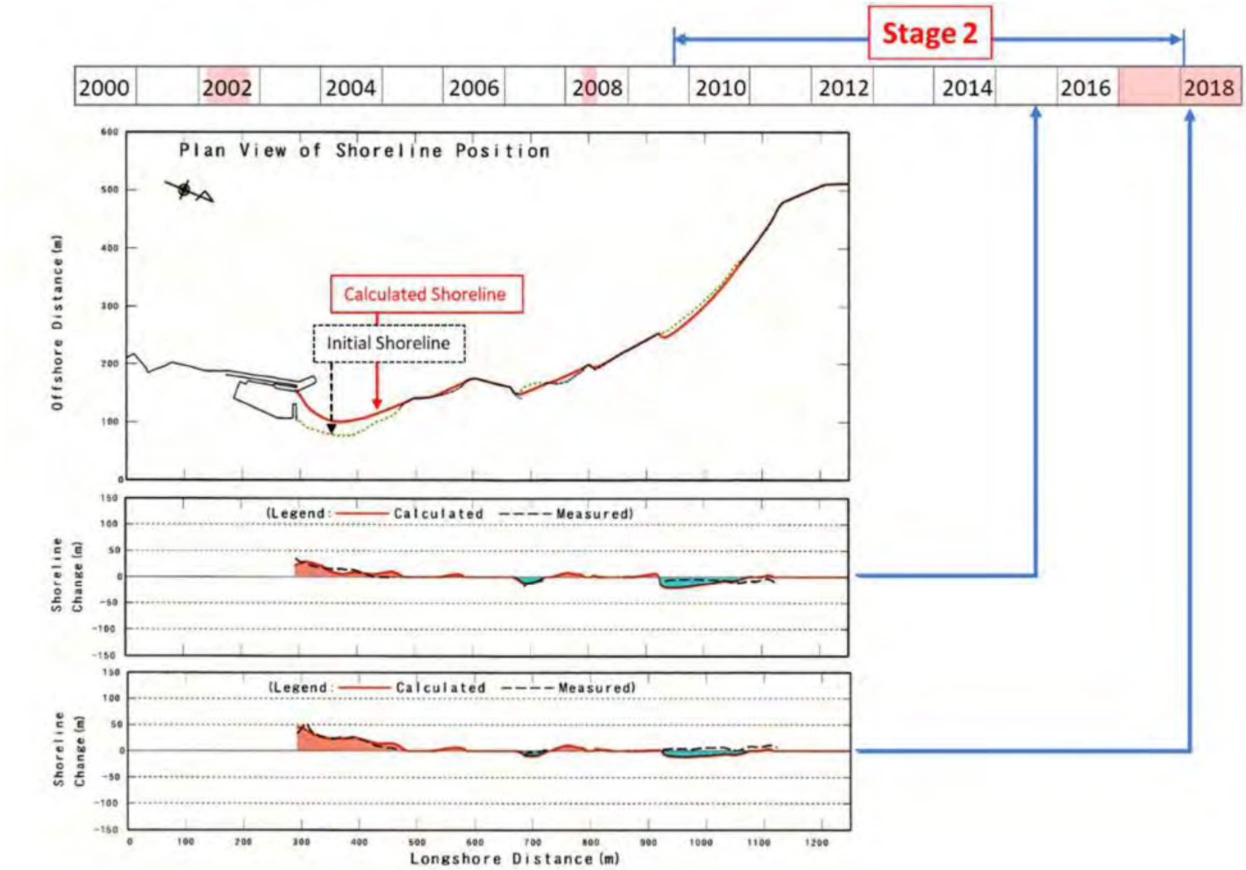


Figure 7-18 Results of reproduction in Stage 2

(5) Reproduction of shoreline change in Stage 3

In Stage 3, dredging work by backhoe is being implemented. Dredging work by backhoe began on December 23, 2016. The dredging work about in the first one year was small-scale. It seems that the work was for excavating a waterway for fishing boats, rather than maintaining a navigation channel. For example, in Photo 7-7, some tools which seem to be ladders are placed on the wave dissipating blocks. These are auxiliary tools which are used to slide and land fishing boats on the beach. Ladders being put such a place imply that port entrance is often closed and fishing boats cannot navigate. Photo 7-8 shows a scene that the study team is leaving the port for regular inspection of the offshore wave gauge. The port entrance is so shallow, water depth of ankle height, that the study team finally can pass the port entrance by pushing the boat with eight people. Photo 7-9 shows the view of the port entrance on January 4, 2018. There is only a narrow waterway that allows one fishing boat to pass at one time.

Photo 7-7 View of port entrance on November 21, 2017

Photo 7-8 View of port entrance on December 5, 2017

Judging from the above situation, the dredging work by backhoe was implemented in 2017, but the amount was considerably small and the dredging work did not affect the shoreline change. Then, the start of the reproduction period in Stage 3 is set as January 2018 as shown in Figure 7-19.

Photo 7-9, which is previously shown as Photo 7-6, shows the initial shoreline. That is, the target shoreline in Stage 2 and the initial shoreline in Stage 3 are the same.

Figure 7-19 Reproduction period in Stage 3

Photo 7-9 Initial shoreline in Stage 3 (Previously shown as Photo 7-6, January 4, 2018, Google Earth)

In stage 3, the amount of sand deposited around the port entrance gradually decreases as shown in Photo 7-10, which is explained in detail in **2.6 Record of dredging works by the government of Saint Lucia after construction completion in 2003**. It is because of the effect of the improved excavation method by backhoe. Although the timing of introduction of the improved method is unclear, it can be understood that the improved method was applied as of March 24, 2018, since the trace of excavation is recognized in the photo on the same day. For this reason, it is necessary to consider the amount of sand excavated from the beach in the reproduction in Stage 3. However, the amount of sand excavation is unknown. In order to evaluate its amount, two factors are taken into consideration; that is, the eroded amount of 2,182m^3 in an area surrounded by a blue line in Figure 7-20, which is estimated based on the results of bathymetric survey conducted on December 30, 2017 and on September 25, 2018, and an excavation period of 6 months. Referencing to Figure 7-21, the longshore sand transport rate of 660m^3/month(= 8000 m^3 / year) is entered into the blue box, while the excavated volume of sand is 360m^3/month(= 2183 m^3 / 6 month) $+\alpha$ and the remaining amount of sand, 660 m^3 / month$+\alpha$, is transported to the north. After several trial calculations, α is set as 140 m^3 / month.

January 4, 2018 March 24, 2018 August 13, 2018

Photo 7-10 Views of port entrance

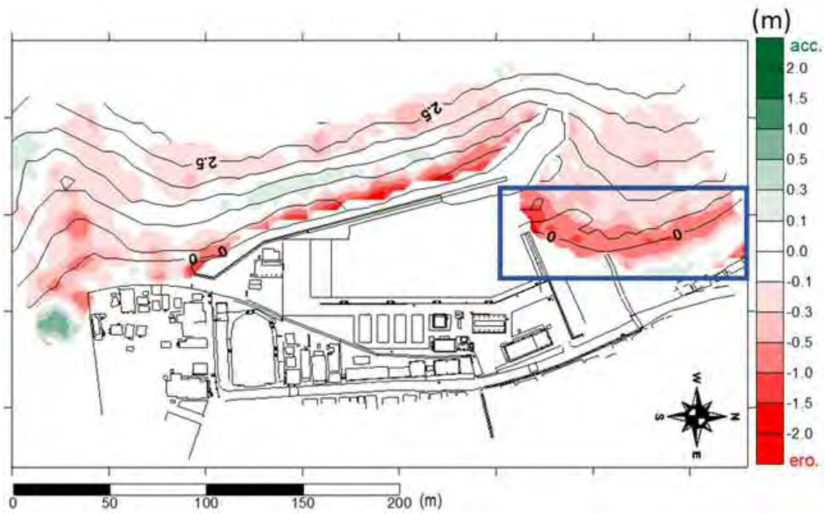


Figure 7-20 Topographic change from November 30, 2017 to September 25, 2018

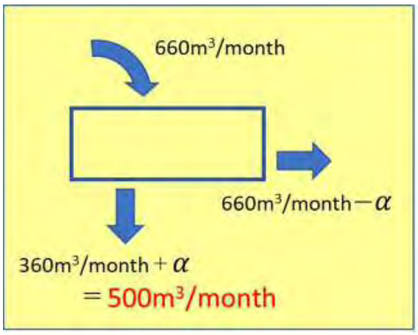
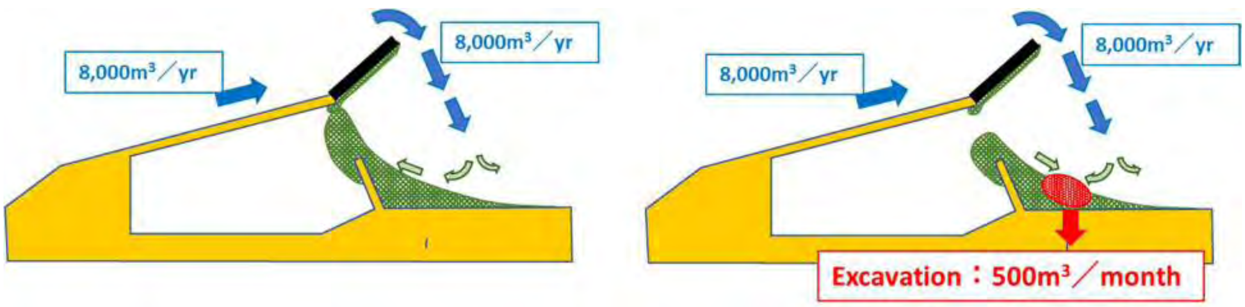


Figure 7-21 Sand budget during a period of excavation at beach

Regarding the excavation period at beach, several trial calculations were repeated confirming the reproducibility of shoreline change, and the excavation period shown in Figure 7-22 is selected because its reproducibility is the best. That is, small-scale dredging at the port entrance had been carried out until February 28, 2018, and the excavation by the improved method began on March 1, 2018. Therefore, the excavation period in the improved method at beach is 6 months.



January 1, 2018 to February 28, 2018 March 1, 2018 to August 2018

Figure 7-22 Sand budget in Stage 3

Figure 7-23 shows the result of the reproduction in Stage 3 from January 2018 to August 2018. The high reproducibility, of the shoreline in progress and target shoreline are confirmed. A black dashed line indicating a surveyed shoreline is not drawn at Sabwisha Beach, alongshore range from 930 m to 1,130 m. This is because the data at Sabwisha Beach in August 2018 is not available.

As confirmed above, the one-line model can reproduce well the shoreline changes in three stages with different conditions of the north beach of the Choiseul fishing port. Thus, this model is judged as applicable to forecast the shoreline changes.

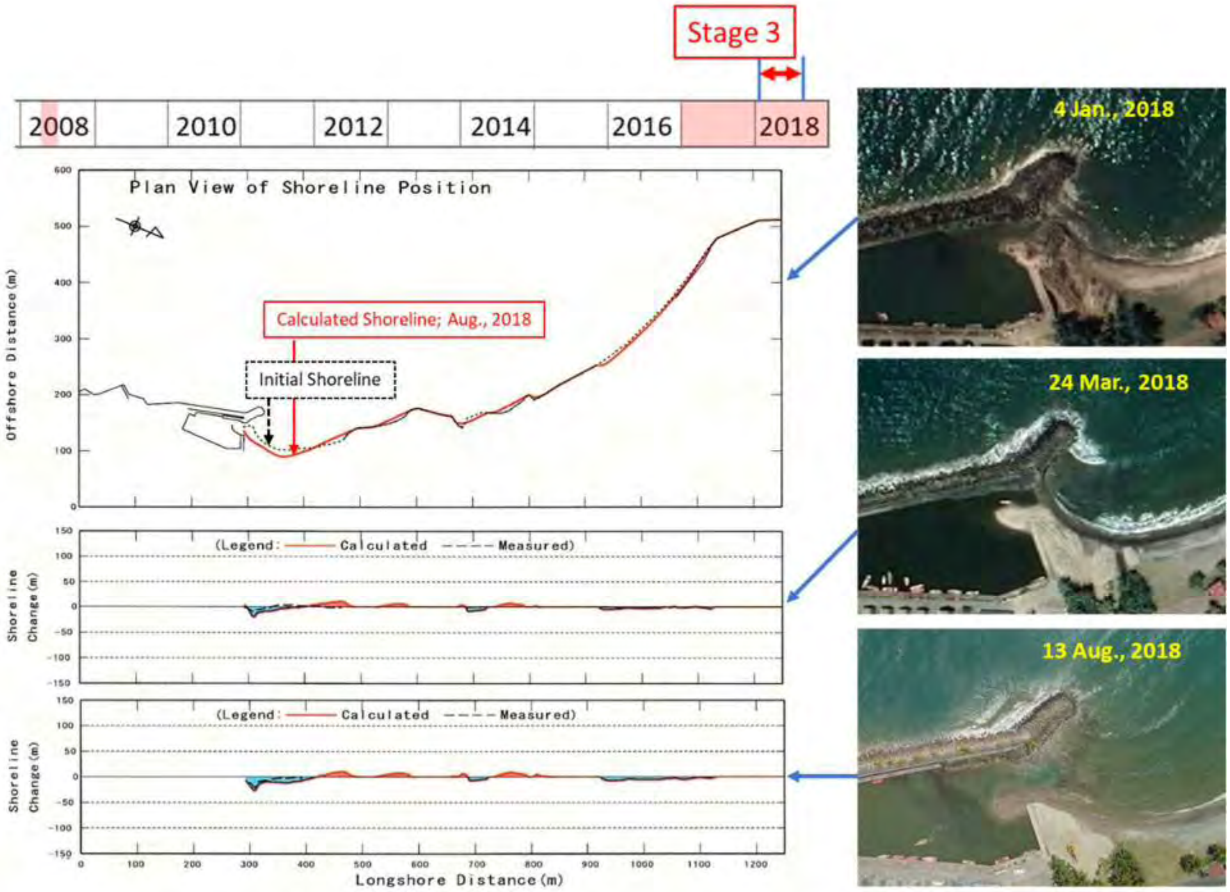


Figure 7-23 Results of reproduction in Stage 3

(6) Study for countermeasures to block Route 1

Figure 7-24 shows simulated shoreline after 30 years without any dredging work by backhoe and countermeasures, taking the reproduced shoreline as of August 2018 as the initial shoreline. The port entrance is completely closed and the shoreline is in equilibrium position. Therefore, all amount of the sand transport of 8,000 m^3/year along the breakwater of the Choiseul fishing port passes by the fishing port to the northward. This simulation aims to roughly determine the layout of countermeasures.

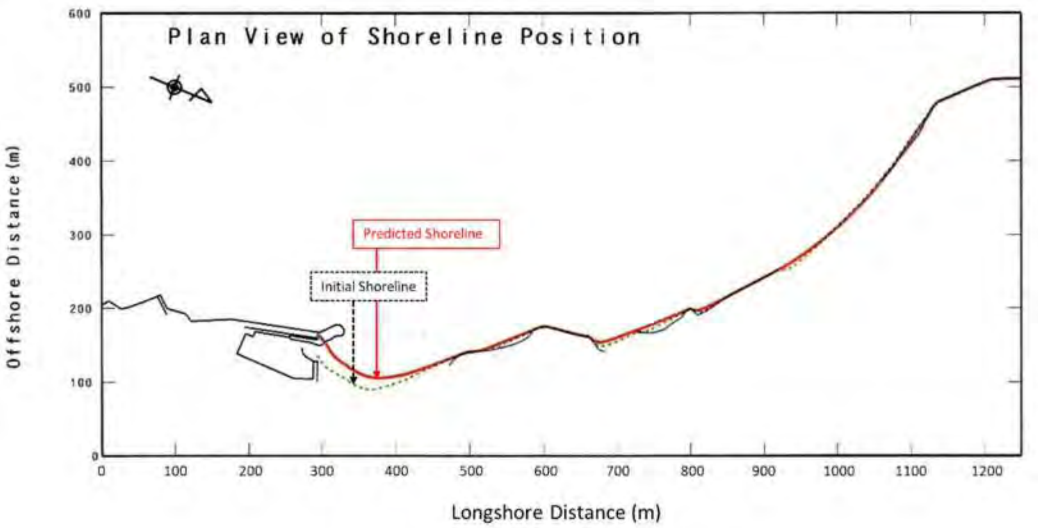


Figure 7-24 Predicted shoreline without countermeasure (30 years after)

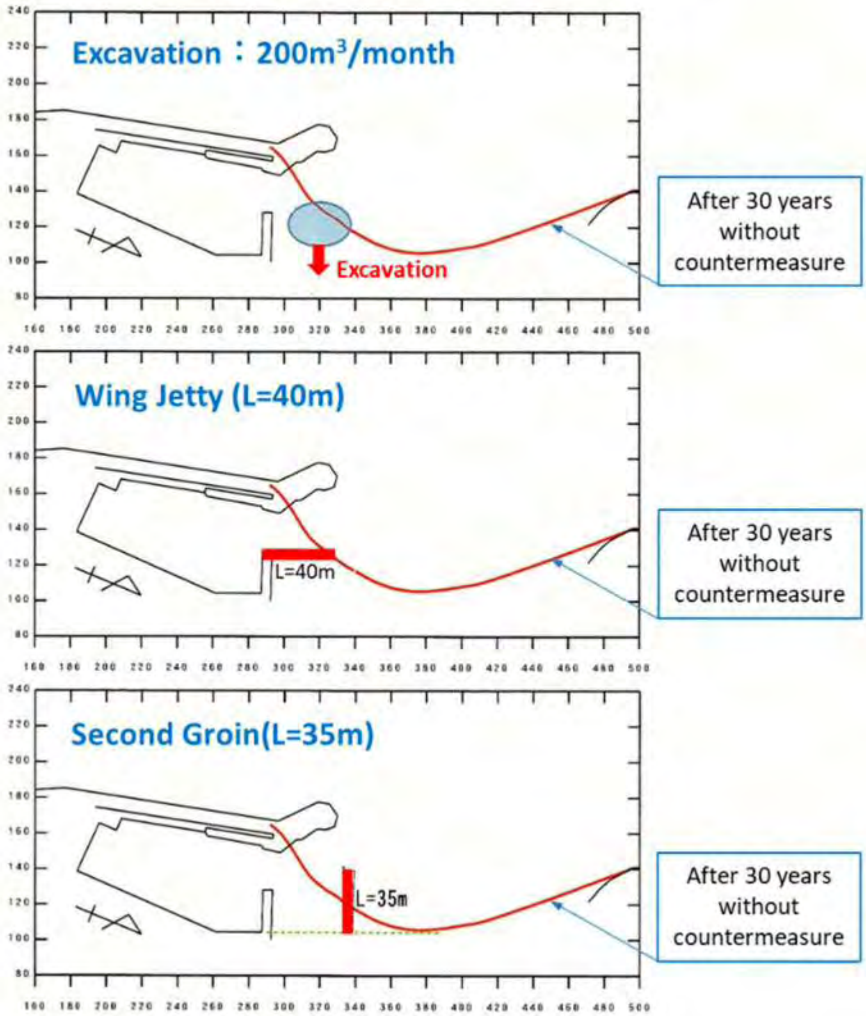
The red line in Figure 7-25 is the shoreline in equilibrium position after 30 years without countermeasures. Three countermeasures shown in the figure are examined:

A. Excavation of 200 m^3/month,

B. Construction of 40 m long wing jetty on the tip of groin,

C. Construction of 35 m long second groin.

In any case, the shoreline as of August 2018 reproduced in Stage 3 is used as the initial shoreline, and the shoreline change for 30 years ahead is predicted.



(Note: Red line shows the shoreline in equilibrium position after 30 years)

Figure 7-25 Examined countermeasures

The results of predicted shoreline of each countermeasure are as follows.

【Excavation of 200 m^3/month】

To confirm the necessary excavation amount for maintaining the initial shoreline on the north beach of the fishing port (300 m to 450 m in the longshore direction), simulation is carried out starting from the case with the excavation amount of 500 m^3/month as the current situation, and cases of 400 m^3/month, 300 m^3/month, 200 m^3/month and 100 m^3/month for 30 years ahead. In case that the amount is set as 500 m^3/month, large erosion would occur on the north beach. In the case of amount 200 m^3/month, the current shoreline could be maintained the best, then this result is explained below.

Figure 7-26 shows the results of predicted shoreline. The north beach of the Choiseul fishing port is stable for 30 years. On the other hand, the shoreline gradually recesses at Sabwisha Beach located approximately 740 m north of the port entrance.

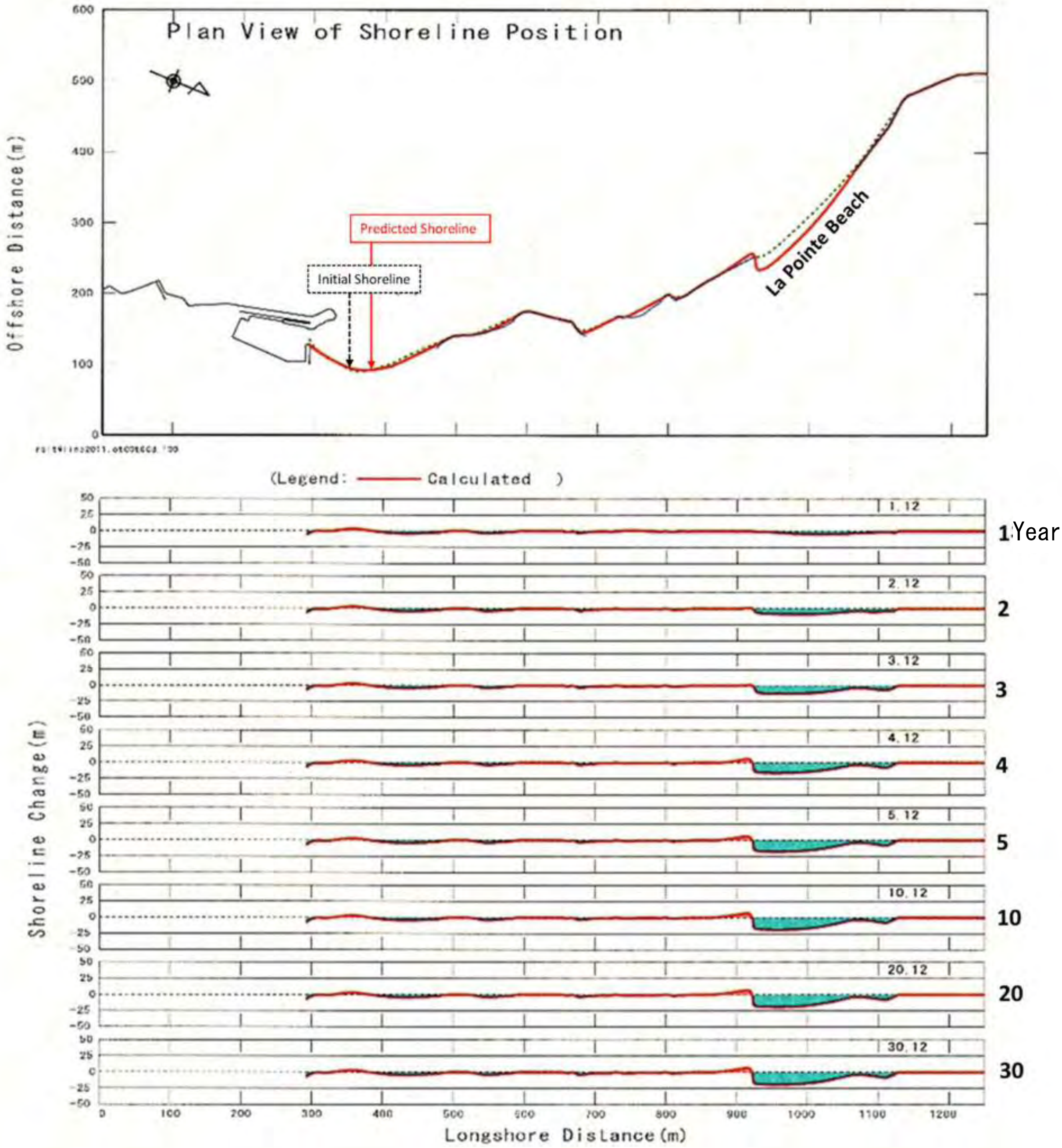


Figure 7-26 Predicted shoreline changes in case of excavation amount of 200 m^3/month by backhoe

【Construction of 40 m long wing jetty on the tip of groin】

Figure 7-27 shows the simulation result of shoreline change in the case that a 40 m long wing jetty is constructed at the tip of the existing groin. The shoreline accretes to the tip of the wing jetty, and as a result, sand is carried underwater toward the fishing port and the port entrance is closed. Even if the wing jetty is extended, the tip is still on the shoreline, thus it is difficult to control the underwater sand movement. After the port entrance is closed, all of the sand transported northward along the breakwater pass by the Choiseul fishing port, and finally reach to Sabwisha Beach. Thus, at La Pointe Beach, the recessed shoreline recovers.

This simulation is carried out based on a premise that the sand in Route 2 (see Figure 7-4) is transported to the north beach smoothly.

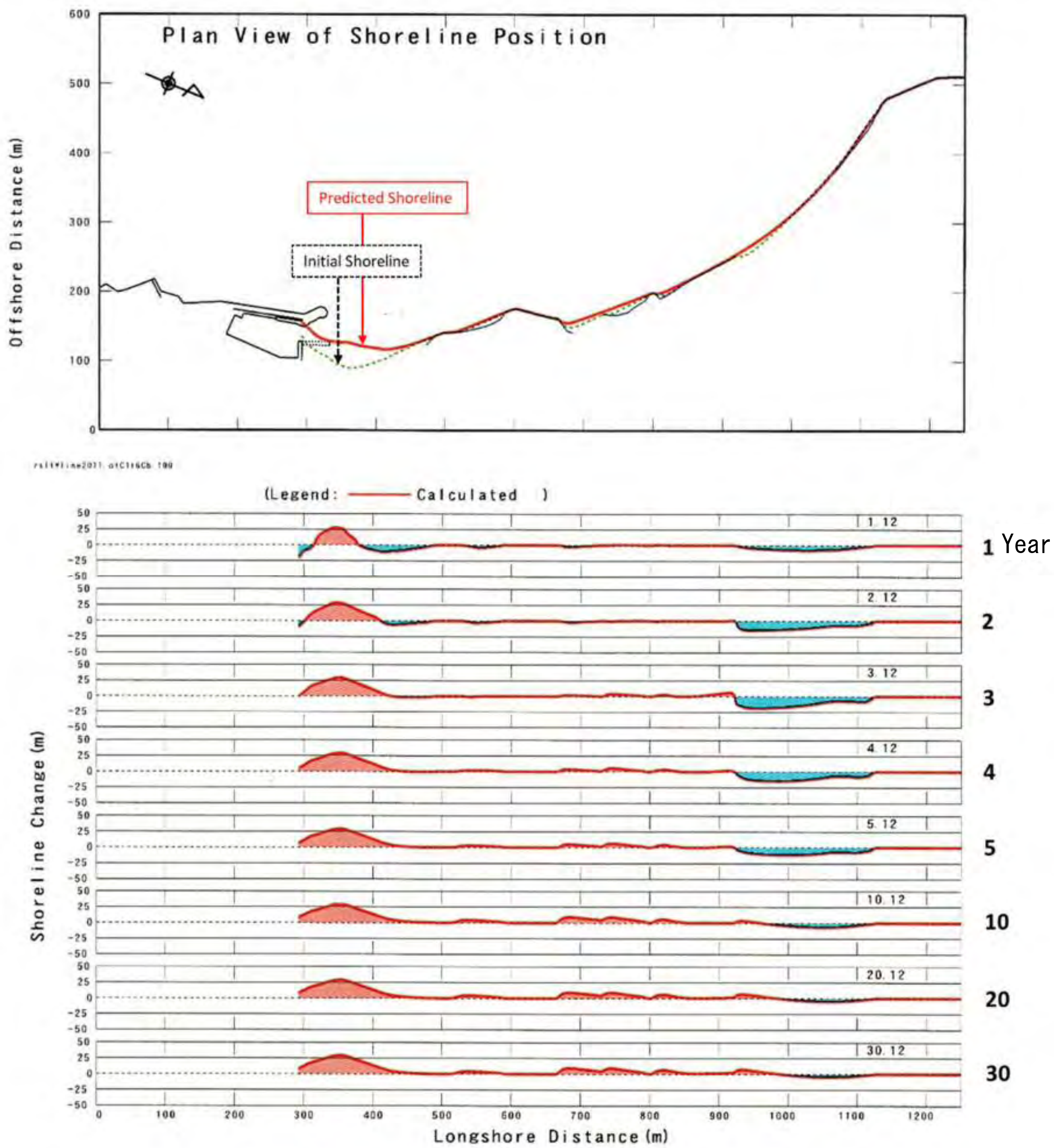


Figure 7-27 Predicted shoreline changes in case of construction of 40 m long wing jetty on the tip of groin

【Construction of 35 m long second groin】

Figure 7-28 shows the shoreline changes in the case that the second groin is constructed on the beach. According to the simulation, sand is not deposited at the port entrance. The lower limit of closure depth is assumed to be -1 m deep. In other words, there is no sand movement in the longshore direction in the areas deeper than -1 m. However, it is possible that sand movement will be found even in the areas deeper than -1 m after construction of the groin. In that case, it can be managed by slightly extending the second groin.

At Sabwisha Beach, the shoreline recesses in the first three years, but recovers almost in 10 years.

This simulation also assumes that sand in Route 2 is smoothly transported to the north beach.

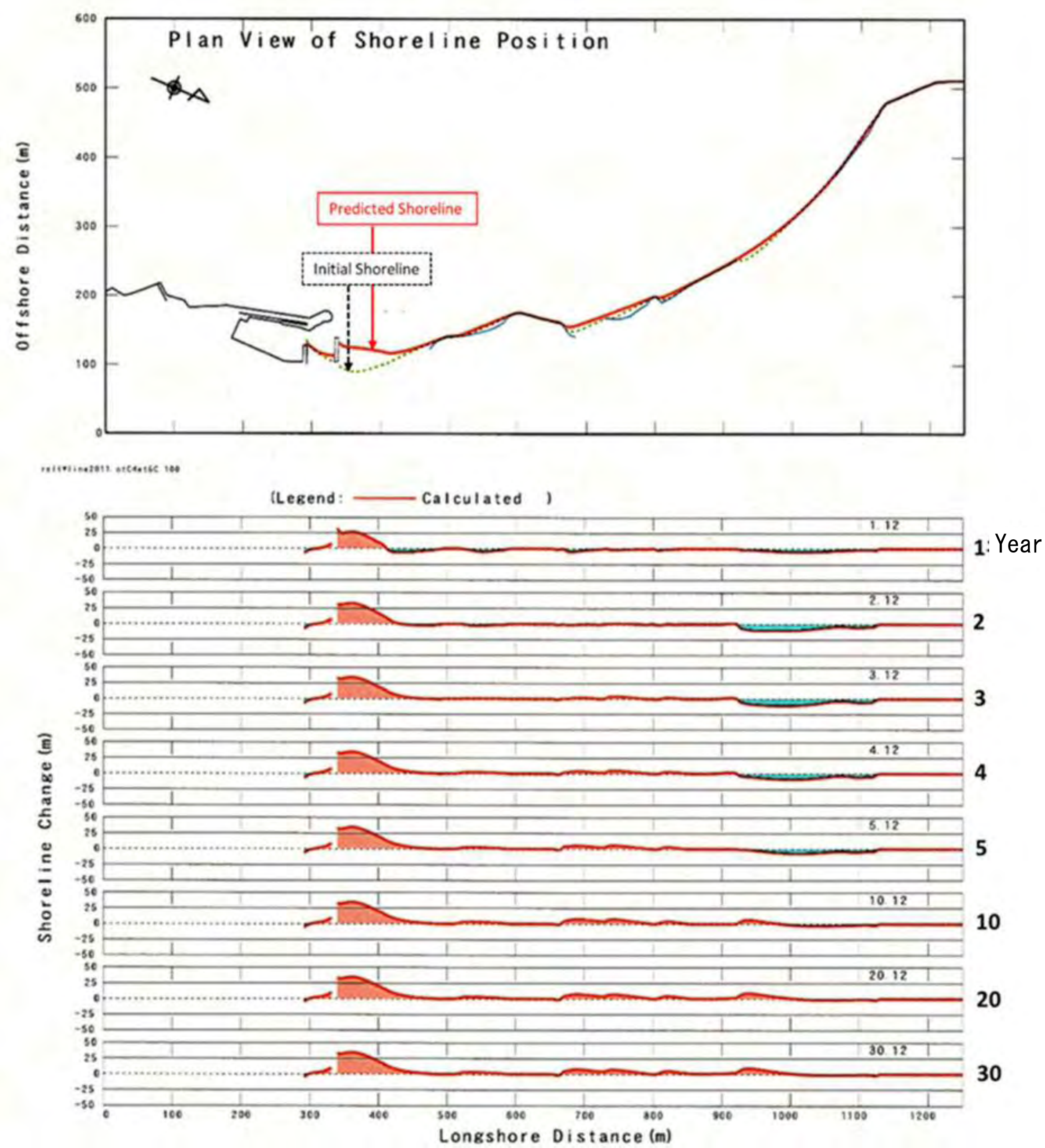


Figure 7-28 Predicted shoreline changes in the case that 35 m long second groin is constructed

(7) Nearshore currents with the second groin

Figure 7-29 shows nearshore currents in a case that the additional breakwater exists but any countermeasures are not constructed. As explained so far, sand is carried by the effects of southward currents circled by a red dashed line.

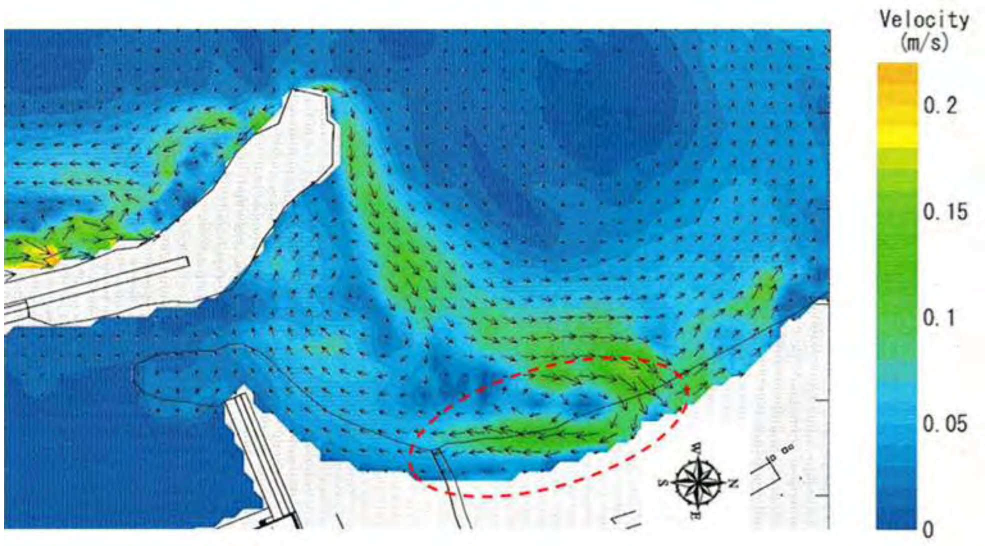


Figure 7-29 Nearshore currents with additional breakwater (same as Figure 7-3)

Figure 7-30 shows the nearshore currents right after the construction of the second groin. Calculation conditions such as topographic conditions and wave conditions are set as the same ones in Figure 7-29, and the only difference is existence of the second groin. The nearshore currents near the tip of the additional breakwater flow to the north beach, and diverge close to the shoreline. There still exist the southward currents. In other words, pattern of the nearshore currents after construction of the second groin is not changed from the one shown in Figure 7-29. The southward currents circled by a red dashed line transport sand, but they are blocked by the second groin before reaching the port entrance. The transported sand is deposited on the north side of the second groin and resultantly an accretion of shoreline occurs.

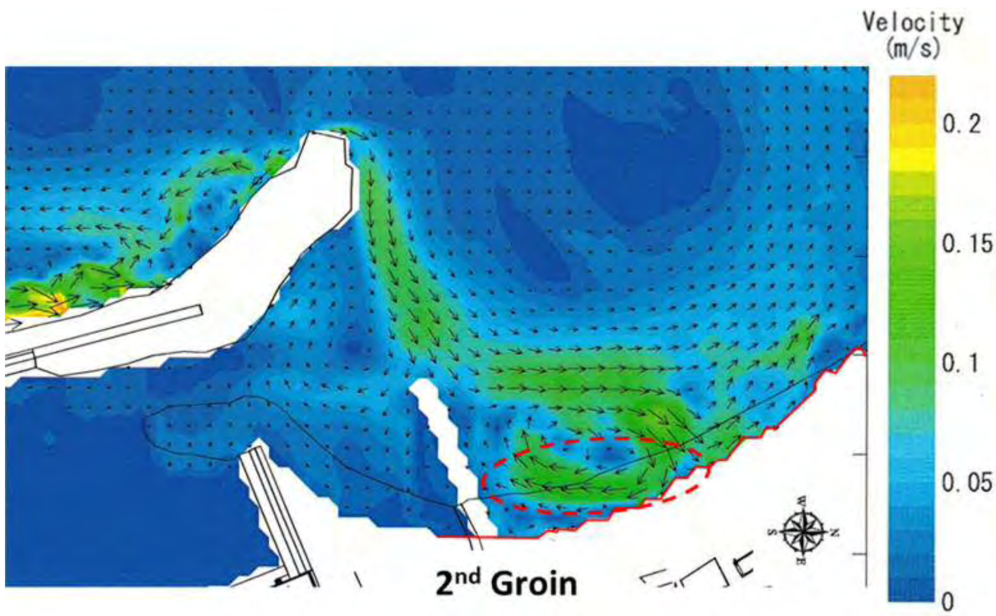


Figure 7-30 Nearshore currents after construction of second groin

Figure 7-31 shows the nearshore currents when the beach on the north side of the second groin accretes. A red solid line is the shoreline of the north beach shown in Figure 7-30. In this simulation, a condition of shoreline accretion is added as indicated by an arrow. As a result, the pattern of the nearshore currents is drastically changed. The nearshore currents near the tip of the additional breakwater flow northward without divergence keeping its velocity. Since the northward nearshore currents occur in accordance with the accretion of shoreline, the further deposition or the accretion of shoreline on the north beach of the second groin is not caused. In other words, this is the self-maintenance mechanism of the shoreline in equilibrium position as explained in Figure 7.5 to 7.8

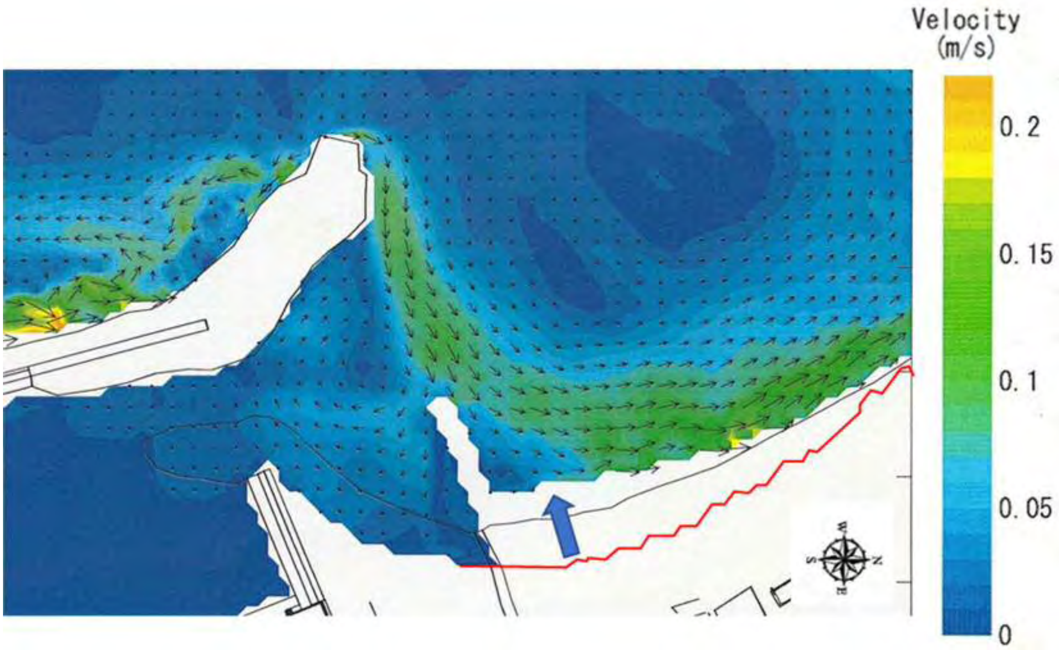


Figure 7-31 Nearshore currents when the shoreline on the north side of the second groin accretes

7.1.3 Countermeasure for changing Route 2

(1) Influence of additional breakwater extension on shoreline

To consider the countermeasure by passing the sand, which is currently transported into the port by Route 2, smoothly to the north beach, effects caused by construction of facilities on the tip of the additional breakwater are studied at first. The upper figure in Figure 7-32 shows the shoreline change after 30 years from the construction of 40 m long wing jetty as a countermeasure (the shoreline changes to the shown position in approximately 5 years). The lower figure is the result of predicted shoreline position after five years in a case of 20 m extension of the additional breakwater.

The only difference of condition between the upper and lower calculations is that the additional breakwater in the lower figure is 20 m longer than the one in upper figure. The initial shoreline of the calculation is the same condition. Although the output time is different, 30 years (upper figure) and 5 years (lower figure), both shoreline change reach the equilibrium position in approximately 5 years, so the difference of output time is not necessary taken into consideration.

According to Figure 7-32, 20 m extension of the additional breakwater results in further accretion of the shoreline at the port entrance. Therefore, countermeasure at the tip of the additional breakwater needs careful consideration.

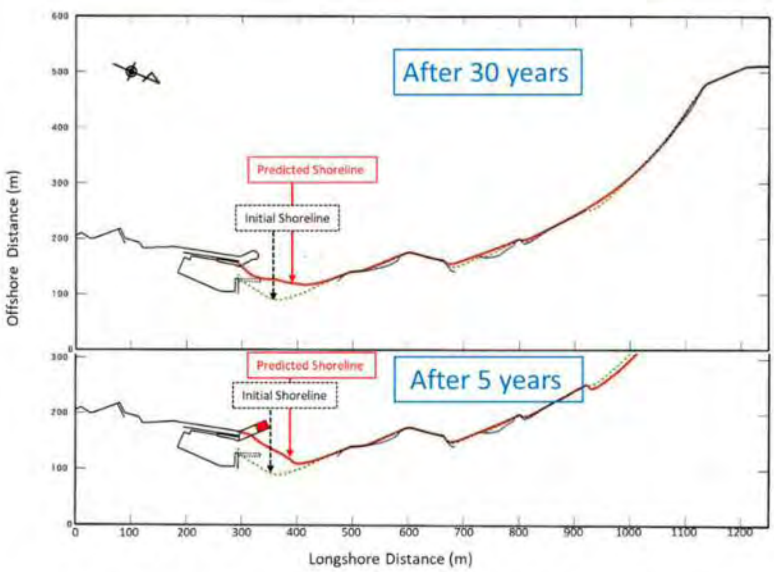


Figure 7-32 Shoreline change with 20 m extension of the additional breakwater

(2) Deposition around the tip of the additional breakwater

The process of deposition in the port before the construction of the additional breakwater is surveyed in detail (refer to **6.4.1 The process of deposition at Choiseul fishing port and surrounding sand budget**). The main points are explained in Figure 7-33.

Figure 7-33 shows locations of -1 m contour from December 6, 2002 to January 4, 2004. Firstly, sand is deposited around the breakwater tip. As the water depth becomes shallow, the water particle velocity due to waves at the bottom increases and the sand becomes easier to be transported in bed-load condition along the back side of breakwater to the interior of the port. In repetition of this, the deposition area extends to the interior of the port. In other words, the deposition around the breakwater tip at first triggers the deposition to extend into the interior of the port. If the deposition is spread in the same mechanism at the tip of the present additional breakwater, it is considered that keeping the sea bottom away from the deposition around the tip of the additional breakwater can lead to prevent the deposition spreading to inside the port.

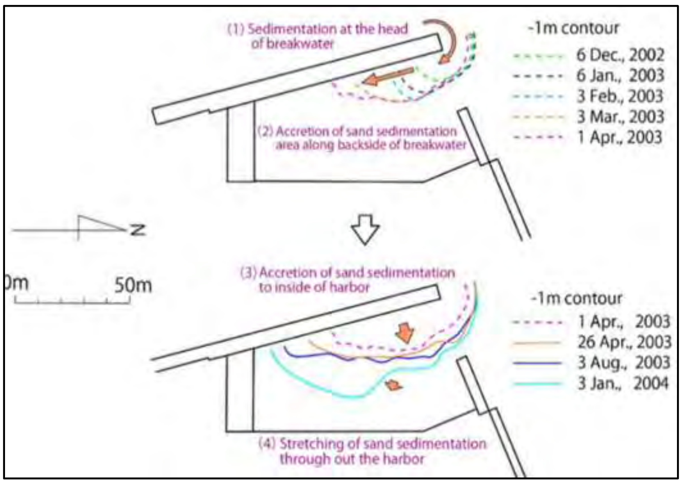


Figure 7-33 Deposition process in the port (before constructing the additional breakwater)
(repost of Figure 6-23)

(3) Nearshore currents passing through the tip of additional breakwater

Figure 7-34 is previously shown in Figure 7-31.

After the second groin is constructed as a countermeasure against deposition, shoreline accrete and the nearshore currents are generated as shown in Figure 7-34. That is, the currents from the tip of the additional breakwater to the north beach will flow northward maintaining the flow velocity without branching. It is efficient if this flow can be used to pass the sand, which currently being transported into the fishing port through Route 2, smoothly to the northern coast.

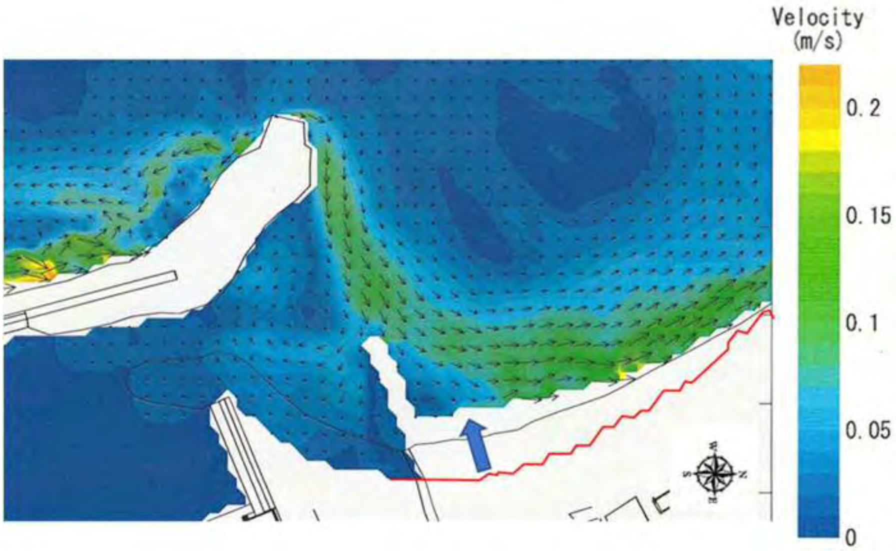


Figure 7-34 Nearshore currents after construction of second groin (Repost of Figure 7-31)

(4) Feasible countermeasure

In the considerations of (1) to (3), it is pointed out that the following three points should be noted as a countermeasure for sand transport through Route 2.

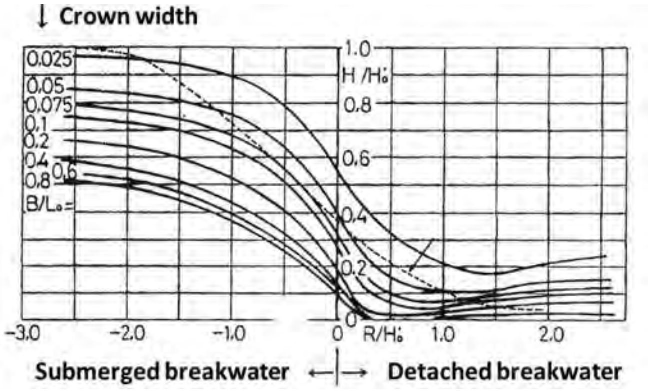
a. The construction of countermeasure at the tip of the wing jetty have to be done carefully as it affects the deposition at the port entrance (related to Figure 7-32).

b. Preventing deposition near the tip of the additional breakwater can keep away from the spread of deposition to the interior of the port (related to Figure 7-33).

c. It is necessary to consider the nearshore currents generated after the construction of second groin is (related to Figure 7-34).

A submerged breakwater with a crown below the water surface can be considered as a structure that satisfies these three conditions simultaneously. The characteristics of the submerged breakwater are described as follows corresponding to a, b and c above.

Figure 7-35 shows the permeability of the submerged breakwater, which is a ratio of transmitted wave height to incident wave height, by means of a hydraulic model study. Each symbol in the figure is defined as H_0' : incident wave height, H : transmitted wave height, R : crown height, B : crown width and L_0 : offshore wave length of incident wave. Since a definition of R is zero at the water surface and it is positive upward, R > 0 means a structure which crown is higher than the water surface, and R <0 (left half of the figure 7-35) means a submerged breakwater. The permeability of the structure which crown is above the sea level is considerably low. On the other hand, the permeability of the submerged breakwater increases as the crown level decreases. In other words, it is expected to have small impact on the deposition at the port entrance when the submerged breakwater is constructed at the tip of the additional breakwater, which is corresponding to a.



(Source: TECHNICAL NOTE OF THE PORT AND HARBOUR RESEARCH INSTITUTE No. 260, Mar.1977, MINISTRY OF TRANSPORT, JAPAN)

Figure 7-35 Permeability of the submerged breakwater

Photo 7-11 is a submerged breakwater constructed at the Niigata West Coast in Japan. Although it cannot be clearly observed because of a structure below the sea level, there is a dark looking structure parallel to the coast on a closer look. This is a submerged breakwater. The crown level of the submerged breakwater is -1.5 m. Since the sandy beach had been lost by severe erosion on Niigata west coast, the sandy beach was artificially nourished. The submerged breakwater has been constructed to protect this artificial sandy beach. A scour, which was not considered before the construction of the submerged breakwater, has occurred at its backside simultaneously with the construction commencement.

Figure 7-36 shows the change of water depth at the time of early stage after the construction of the submerged breakwater. The location in the figure is the place enclosed by the yellow line in Photo 7-11. Red area has been scoured and the scoured topography is understood to be formed parallel to the submerged breakwater (it could be known as scoured channel). Figure 7-37 shows the changes of profile in a cross section. Comparing shore side water depths of before (1987 and 1989) with after (1991 and 1993) construction of the submerged breakwater, the scored depth is approximately 2.5 m.

When the submerged breakwater is constructed at the tip of the present additional breakwater, the back side (shore side) will be scoured. Then, the sand, which is transported around the tip of the additional breakwater, will be transported into the scoured channel. Since the scour is considered to be caused by the strong turbulence generated by the waves breaking on the submerged breakwater, the sand cannot stay there because of the turbulence. In other words, there is no deposition near the tip of the additional breakwater that becomes the trigger for the deposition in the port, which is corresponding to the point b. above.

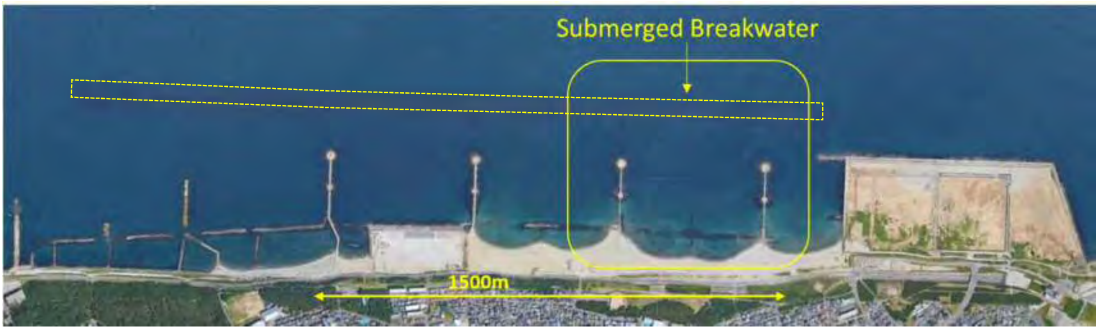


Photo 7-11 Submerged breakwater constructed at Niigata West Coast in Japan（Google Earth）

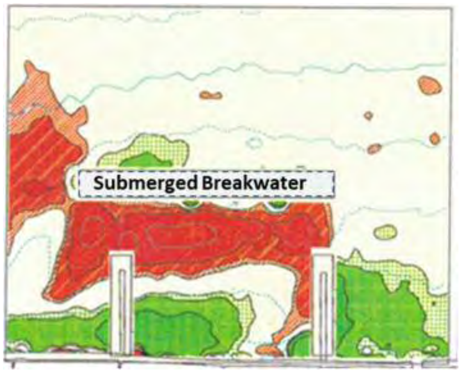


Figure 7-36 Water depth variation (May 1987 to June 1993)

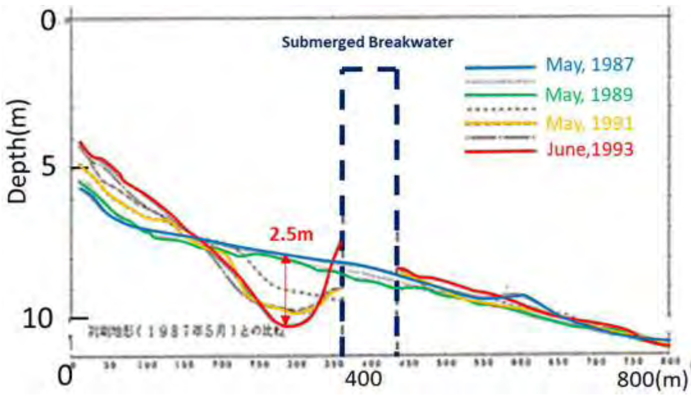
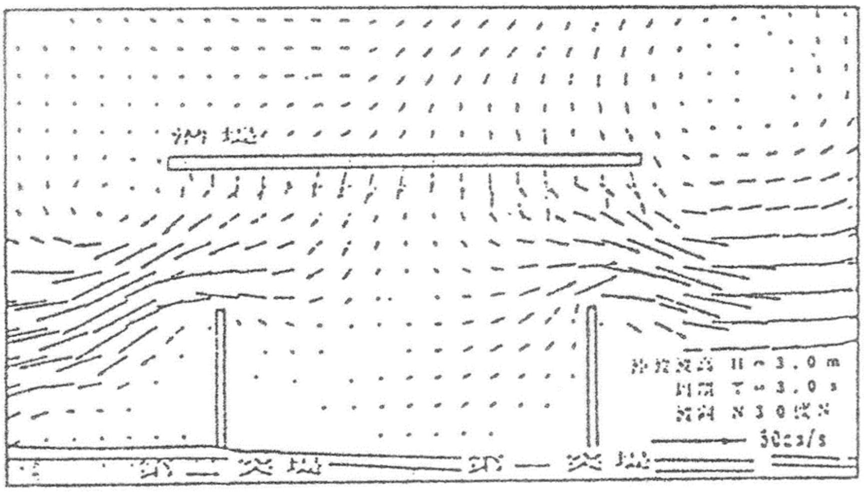


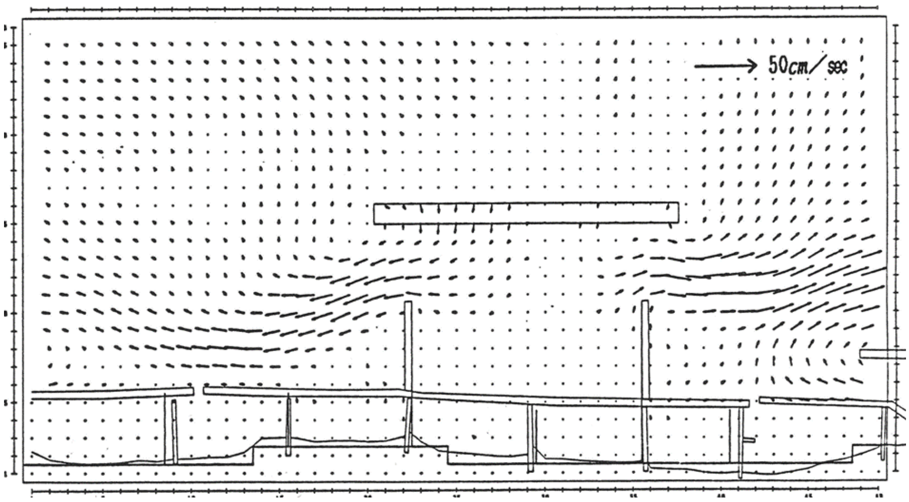
Figure 7-37 Profile changes at the scoured channel

Figure 7-38 shows the reproduction of the nearshore currents around the submerged breakwater by hydraulic model experiment and numerical simulations when scour was identified in the early stage after construction on the Niigata West Coast (Figure 7-36). There are strong currents at shore side of the submerged breakwater. This is because the water mass plunges into the shore side when the wave crest passes over the submerged breakwater. Groins, which are constructed behind the submerged breakwater, aim to prevent the nourished sand from carrying off by the strong current.

Concerning nearshore currents simulation with the second groin as shown in Figure 7-34, the tip of the additional breakwater remains as it is. Even so, currents around the additional breakwater to the northern beach is generated. It is expected that these currents will be further intensified if the submerged breakwater is constructed at the tip of the additional breakwater. Sand that has deposited to the scoured channel becomes in suspension by turbulence due to wave breaking on the submerged breakwater. And the sand is transported easily to the northern coast by intensified nearshore currents, which is corresponding to point c..



(a) Hydraulic model experiment



(b) Numerical simulation

Figure 7-38 Nearshore currents around submerged breakwater at Niigata in Japan

From the above, submerged breakwater is determined to be a countermeasure that satisfies above three points for sand transport through Route 2.

7.1.4 Idea of countermeasures

Figure 7-39 shows the idea of the countermeasures, based on the above consideration.

【Blocking of sand transport in Route 1】

The second groin is effective. When it is constructed, an equilibrium shoreline configuration is formed on the north side of second groin. The shoreline shape is considerably stable and does not accrete further. That is, the sand transport in Route 1 can be blocked.

【Route change of sand transport in Route 2】

Concerning Route 2, a submerged breakwater is constructed on the extension line of the present additional breakwater. Then, followings are expected.

a. Since the submerged breakwater is a permeable structure, there is a few influence on the beach behind it.

b. Since the back of the submerged breakwater (shore side) is scoured, the deposition which leads the water depth to shallow does not occur.

c. The submerged breakwater accelerates the nearshore currents, by which sand is transported in suspension to the north.

In control of sand transport, blocking sand transport is typical. However, there is no example of countermeasures making the sand smoothly pass through, so only a few experiences and technology have been piled. Thus, a hydraulic model experiment is necessary to carefully study and consider the details of the countermeasure.

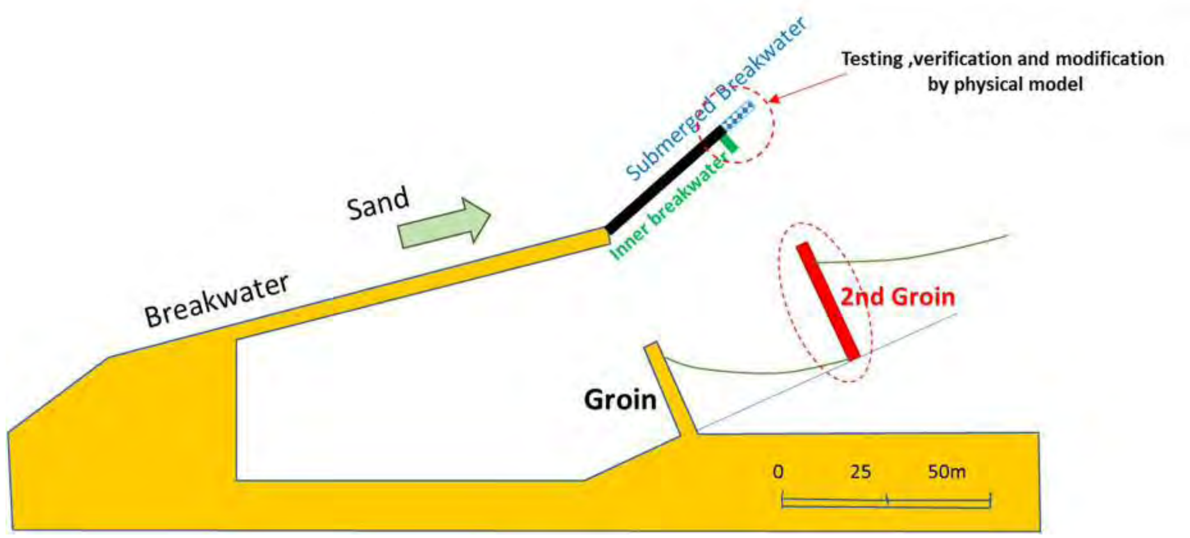


Figure 7-39 Idea of countermeasures

7.2 Consideration for hydraulic characteristics of countermeasure by hydraulic model experiment

7.2.1 Conditions of hydraulic model experiment

(1) Setting of natural condition

According to the result of wave hindcasting during 2000 to 2017, five best wave heights are picked up each year. In Table 7-2, the average values of these wave factors are listed. The wave direction is indicated with the clockwise angle defining N as 0. The average value of whole period is made as the target wave of experiment. That is, the significant wave height is 0.82m, the significant wave period is 6.99s, and the wave direction is S (= 183 degrees).

Table 7-2 Average value of wave factors in annual 5 best wave heights

Year	$H_{1/3}$ (m)	$T_{1/3}$ (s)	Dir. (deg)
2000	0.85	6.38	191
2001	0.83	7.16	187
2002	0.76	7.06	173
2003	0.68	5.90	167
2004	0.91	6.72	181
2005	0.69	6.80	170
2006	0.74	8.34	187
2007	0.83	6.32	175
2008	0.88	4.74	182
2009	0.79	7.94	178
2010	0.89	5.88	226
2011	0.76	8.56	181
2012	1.22	6.74	196
2013	0.77	7.32	178
2014	0.64	6.66	172
2015	0.73	9.10	197
2016	0.80	7.38	176
2017	0.98	6.90	183
average	0.82	6.99	183

Considering the small tidal range, 0.16 m, in Choiseul and efficiency in the experiment, only one representative tide level is selected in the experiment, that is, the mean tide level of +0.23 m.

(2) Outline of physical model

The experiment is carried out using the wave basin of 21 m wide, 40 m long and 0.8 m deep. The wave generator in this wave basin has an ability to generate unidirectional irregular waves in the range of 0 to 0.25 m of wave height, 0.5 to 4.0 s of the period.

Figure 7-40 shows the Choiseul fishing port and the bottom topography around the port that are reproduced in the wave basin. The model is 1/15 of horizontal scale and 1/15 of vertical scale with no distortion. The bottom topography is reproduced with the mortar surface fixed bed. The water depth (m) of contour line in the figure is the ones in actual site.

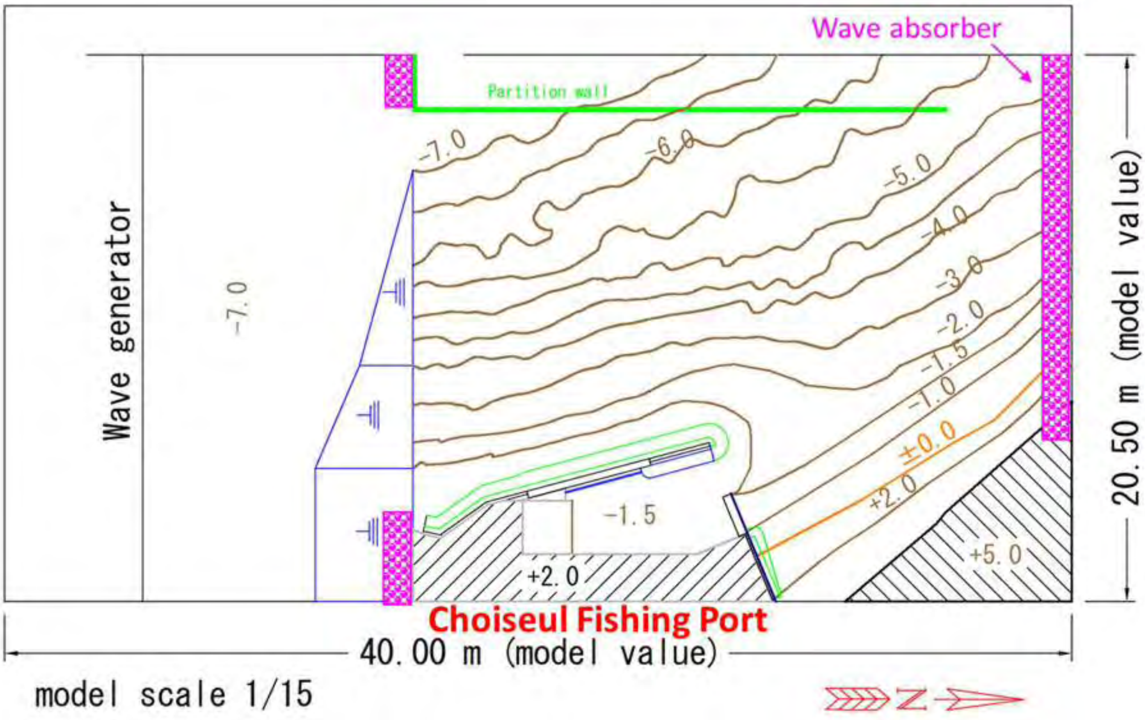


Figure 7-40 Hydraulic model in wave basin

Experimental wave factors in case of 1/15 model are set as follows according to the Froude similitude.

$$\text{Significant wave height} = {}^{0.82\text{m}}/_{15} = 5.5\text{cm}$$

$$\text{Significant period} = {}^{6.99\text{s}}/_{\sqrt{15}} = 1.80\text{s}$$

Using no distorted model and following the Froude similitude, reproduction of various phenomena related with the wave deformation such as the refraction, the shoaling, the wave breaking and so on are guaranteed.

Topography changes such as the deposition (sedimentation) and the erosion (scouring) cannot be reproduced by the fixed bed model experiment. Therefore, the methodology frequently used is that the injected tracers are tracked, and sediment transport at site and topographic changes such as deposition and erosion are inferred. Material which is almost same as sand in particle diameter, is smaller than that of sand (2.65) in the specific gravity, and is easy to obtain, is selected as the tracer in general. The particles of ion exchange resin are utilized as the tracers in the model experiment of Choiseul fishing port (Photo 7-12). The median grain size of this material is 0.68 mm and the specific gravity is 1.26. However, since there is no similarity law related to the movement of particles of ion exchange resin, it is required to testify that they are useful enough for understanding the sediment transport and the topographic change in the field. This is testified performing the experiment for reproduction of sand deposition in the port in 7.2.2.

Photo 7-12 Particles of ion exchange resin utilized as tracers
(Median grain size is 0.68 mm and specific gravity is 1.26)

(3) Outline of experiment procedure, tracking of tracers and the display method

After confirming the situation with almost no water movement in the wave basin, the experiment is commenced starting up the wave generator. Effective duration of wave action is 30 minutes. The first 10 minutes is the waiting time until the waves and currents become steady. Various measurements are made in the remaining 20 minutes.

The measuring items are the tracer tracking, the velocities by electromagnetic current meters, current observation using floats or dyed water, wave profiles by capacitance-type wave gauges. Out of these, the tracer tracking is explained in this part. Details of other measurement items and the measurement points are referred to Annex.

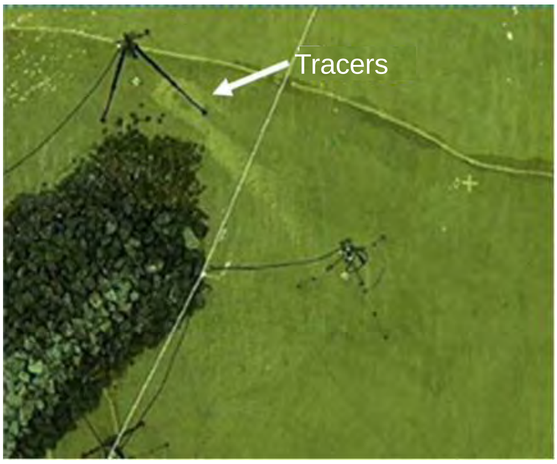
Tracers are injected at 10 minutes after starting up the wave generator. One measuring cup of tracers which is 156 g weight are injected in an injection point. The movement situations are taken by the video-camera installed above the wave basin on the ceiling of the building, and the still-picture is analyzed every several minutes. Once an experiment is finished, the tracers spread on the fixed bed are collected by the area and measured their weight. Every time, the collection is done carefully so that the tracers do not remain at the time of next experiment. In case that there is a possibility that tracers injected in different points are mixed during experiment due to the closeness of injection points, the experiments with the same condition are performed repeatedly and the tracers injected separately. The results of tracking are superimposed all together in the same figure (e.g. later shown Figure 7-44).

From the movie of video-camera, generally still picture of every 4 minutes is picked up to analyze the distribution of tracers. When the movement of tracers is fast, the pick-up of every 1 minute is done. Figure 7-41 shows an expression example of tracer distribution. The display of tracers at the same time is made with the same color and,

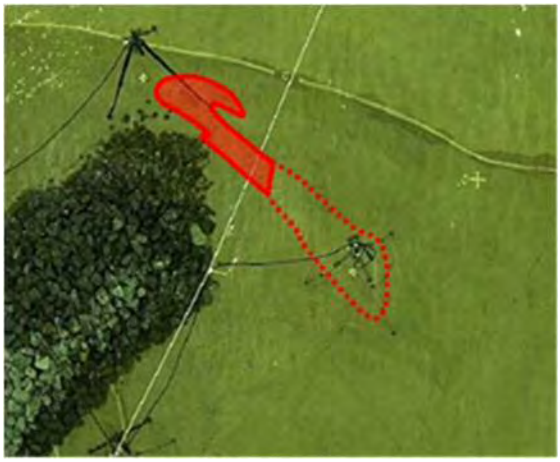
＊ the area where tracers are densely distributed is filled,

＊ the area where tracers are lightly and sparsely distributed is surrounded by dashed lines.

As seen in Figure 7-42, the distribution of tracers read from the still-pictures are superimposed so that the movement of tracers is easily understood. Tracer injection point is marked by white ☆ mark below.



(1) Picture of tracer distribution



(2) Sample expression of tracer distribution

Figure 7-41 Picture and sample expression of tracer distribution

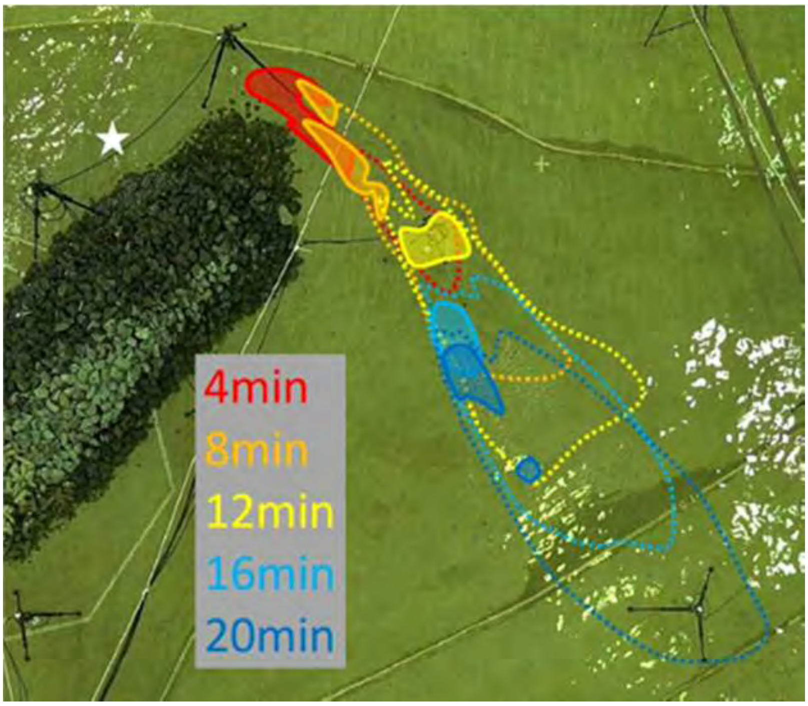


Figure 7-42 Expression example of tracer movement

7.2.2 Reproduction of sand deposition in the port by combining fixed bed model and tracer techniques

What is important in the model experiment combining the fixed bed model and tracer (ion-exchange resin) technique for studying the countermeasures against the deposition in Choiseul fishing port is to confirm reproducibility by this method with respect to the past sediment transport phenomena (sand inflow and deposition in the port). The concrete confirmation method is to reproduce the past deposition in the fishing port. In the process of experiment for reproduction, how to interpret the data obtained also has to be examined.

Characteristic patterns of the past port deposition in the fishing port:

①in the first period with no additional breakwater; a pattern that sand deposited after going around the tip of breakwater and being carried along the breakwater,

②in the second period after construction of additional breakwater; a pattern that sand from north beach deposited after passing by the tip of groin.

While the sediment transport mentioned in ② is possible to be reproduced by numerical simulation (calculation of shoreline change), the simulation for ① is difficult because the mechanisms of sand wraparound and transportation along the breakwater have been unexplained enough.

(1) Reproduction of deposition pattern in the fishing port in the first period with no additional breakwater

Figure 7-43 schematically shows the route of sand transport causing the deposition in the port before the construction of additional breakwater. Namely, the sand transport toward the north in front of the breakwater is separated to the route A which wraps around the tip of breakwater and the route B which is transported to further north direction. The sand of route A, which enters into the port wrapping around the tip of breakwater, is transported further along the back of breakwater and deposits. Most of the sand of route B is transported to the north (right) direction. In the northern (right) side of the groin, slight deposition and advancement of shoreline occurs.

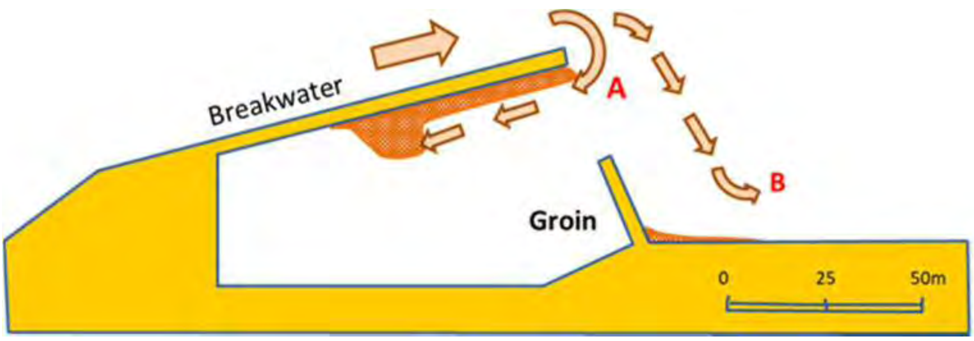


Figure 7-43 Schematic diagram of the routes of sediment transport at the initial construction stage (no additional breakwater) (repost of Figure 7-1)

Figure 7-44 shows the movement situation of the tracers injected at 4 points.

As the most notable route is the route A (Figure 7-43) which relates directly with the deposition in the port, the movements of tracers injected at point 1 and 2 are specially focused. Main group of tracers injected at point 1 moves wrapping around the tip of breakwater drawing an arc. However, the tracers injected at point 2 remain the injection point without movement. In other words, although the sand transport wrapping around the tip of breakwater is reproduced, the sand transport toward the interior of the port along the breakwater is not reproduced. Therefore, it becomes important how to interpret and understand this result.

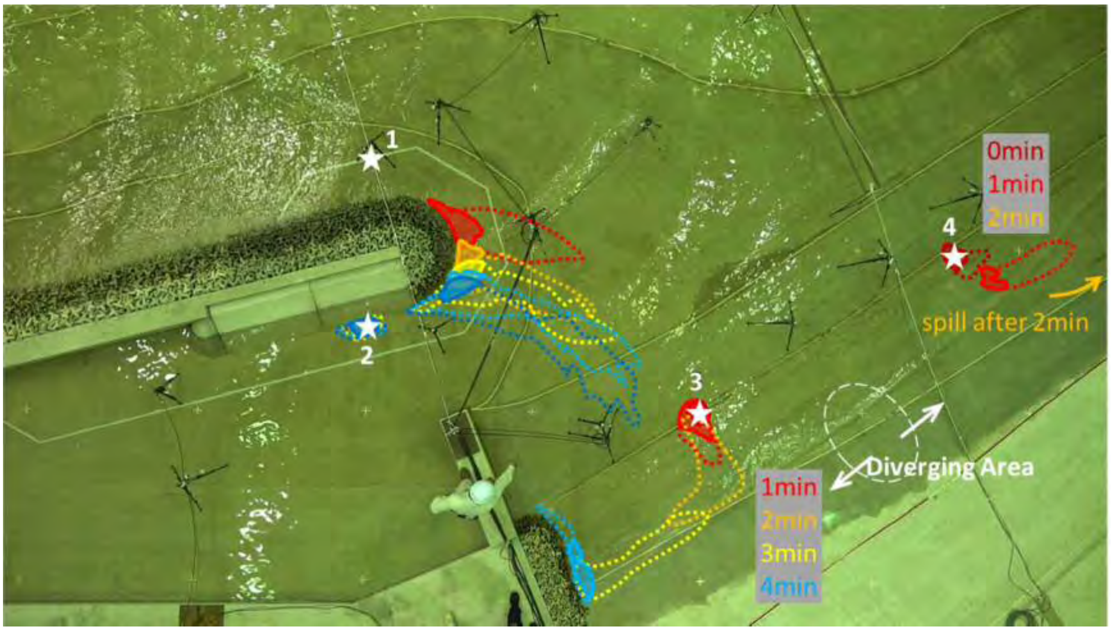


Figure 7-44 Movement situation of tracers injected at 4 points

The tracers instantaneously injected one time at point 1 are tracked in the experiment. On the contrary, the alongshore sediment transport is rolled on continuously from the south (left side) near the injection point 1 at the site. The tracers must be injected continuously for the reproduction of this situation. However, tracers are injected instantaneously in the experiment, the actual sediment transport at the site must be inferred based on the obtained data. Also in the site, the sand is considered to be transported through the same route as that of experiment. The sand deposits and the water depth becomes gradually shallower at the area circled by dashed line in Figure 7-45, where the tracers deposit in the experiment. It is because the wave and current forces acting on the bottom become stronger along with the water depth becoming shallower, and the sand is transported further.

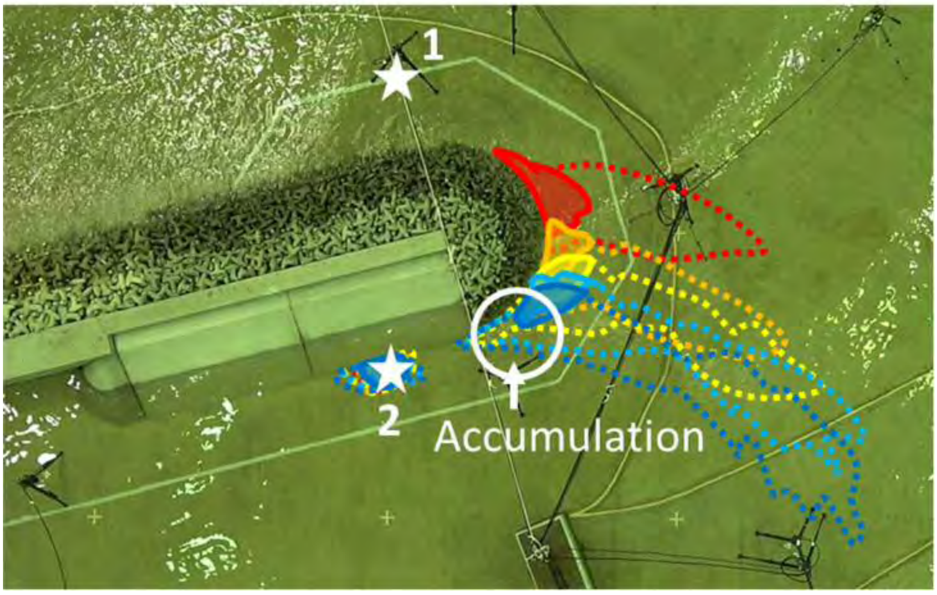
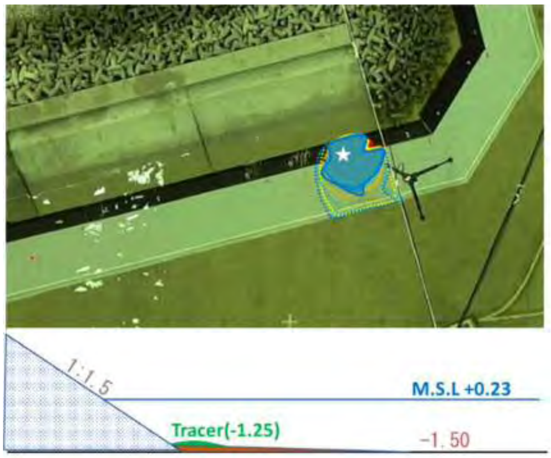
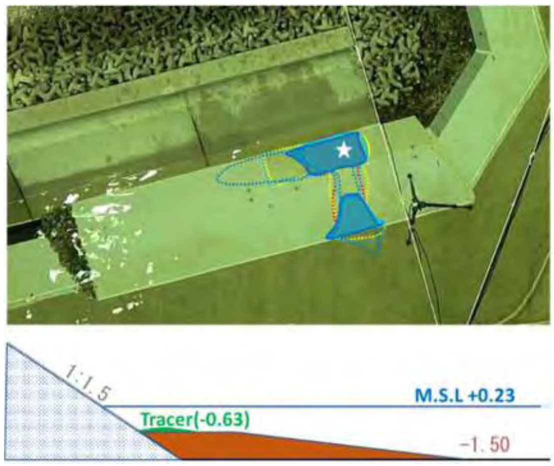


Figure 7-45 Inferred place to cause the sand deposition at the site

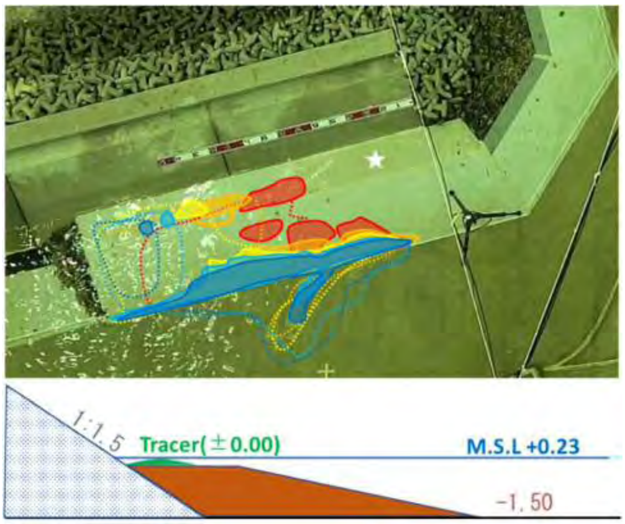
The experiment has been executed to confirm sand movement and topographic change inferred from the tracking result of tracers injected instantaneously. Under the experimental condition that the deposited topography is physically simulated on the sea bottom around the tip of breakwater, the tracer movements are tracked. An area appearing white around the breakwater in every photo shown in Figure 7-46 is the simulated deposited topography. The cross section and the tracer injection point are shown underneath of each photo. Almost no movements of tracers are confirmed in the case that the injection point is -1.25 m sea bottom level, see Figure 7-46 a). In the case of the sea bottom level of -0.63 m, Figure 7-46 b), tracers moving to the interior of the port on the horizontal bed are found. The tracers slipped down from the slope of deposited topography remain there due to the deeper water depth and the weaker wave action. When the sea bottom level become ±0.00 m, Figure 7-4 c), the tracers move further to the interior of the port. There exist tracers on the slope and the bottom of slope as well. These tracers are widely distributed to the interior of the port. This distribution does not mean the tracers' movement on the slope and the bottom of slope to the interior of the port, but this is because the tracers slip down the slope while moving on the horizontal part of deposited topography. Therefore, it is appropriate that the sand is transported over the shallow area if such a topography is formed by deposition.



a) Deposited topography G.L. -1.25m



b) Deposited topography G.L. -0.63 m



c) Deposited topography G.L. ±0.00 m

Figure 7-46 Movement of tracers on the deposited topography around the tip of breakwater

Figure 7-47 shows the actual process of sedimentation in the port. The initial deposition occurs touching to the breakwater at the port mouth and the deposited topography grows up gradually to the interior of the port. Before long, it enlarges to the all areas in the port. The movements of tracers, observed under the experimental condition with the deposited topography, well correspond to the actual process of sedimentation in the port.

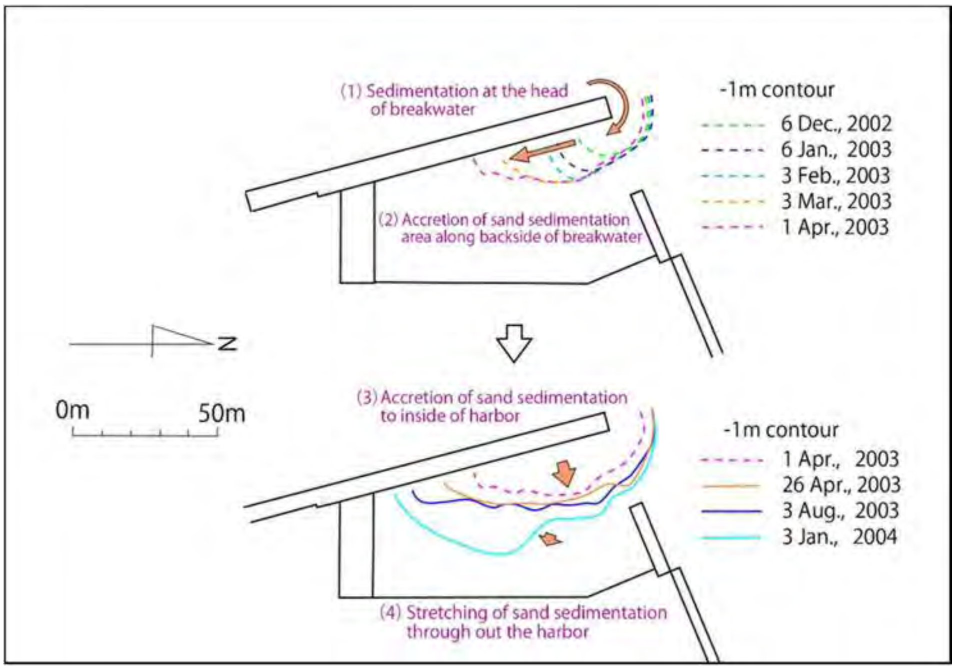


Figure 7-47 Deposition process in the port (repost of Figure 6-23)

Returning to Figure 7-44 again, the movement of tracers injected at point 3 and 4 are focused.

The tracers injected at point 3 are carried along the shoreline in the direction to the groin and accumulate near the base of the groin. The speed of tracers is fast: it is noted that an interval of tracking tracers is 1 minute. The shoreline is inferred to advance in the area adjacent to the base of groin. This shoreline change can be reproduced with the numerical simulation, see Figure 7-48. The tracers injected at point 4 are washed away to the north direction (to right) in 2 minutes after injection. This movement corresponds to the sand transportation through route B in Figure 7-43. Also, it is found by observing nearshore currents by means of dyed water that there was an area making current separated to the south and the north (left and right sides) around the area circled by dashed line between the injection points 3 and 4.

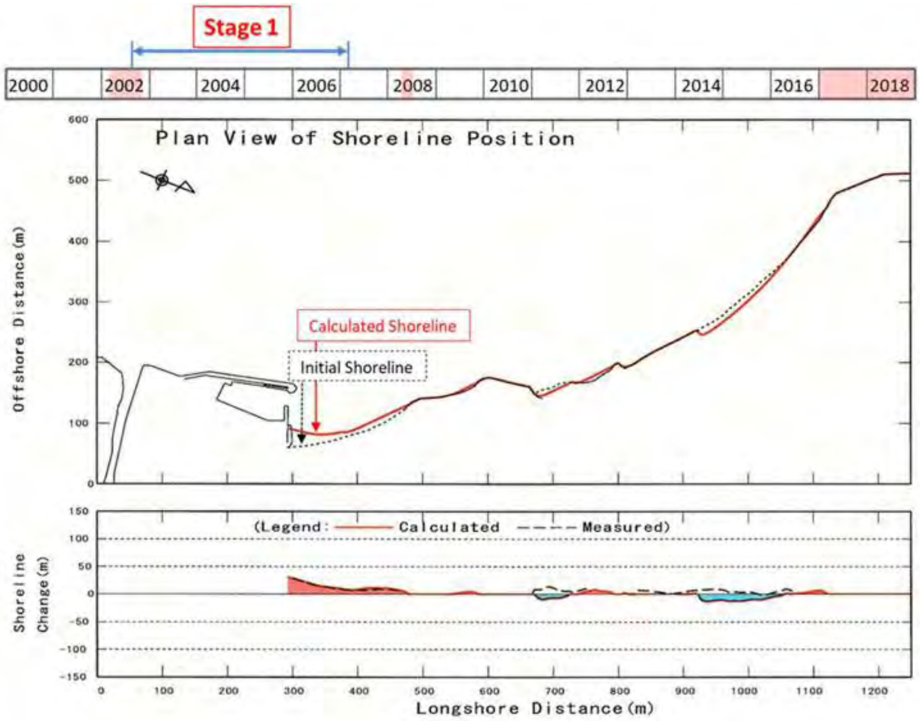


Figure 7-48 Reproduction of shoreline advancement near groin base (repost of Figure 7-16)

(2) Reproduction of deposition pattern in the fishing port in the second period with additional breakwater

Figure 7-49 shows the schematic diagram of sand transport after construction of additional breakwater. The sediment transport going toward the north (right direction) in front of breakwater is separated into the routes A and B. The former wraps around the tip of additional breakwater and go into the port. The sand of route B is further separated to the route C, through which the sand is transported to and deposits in the beach sheltered by the additional breakwater, and shoreline is advanced. After the shoreline advancement reaches near the tip of groin, the sand transported through the route C flows into the port wrapping around the tip of groin. As a result, the sand deposits at the port side of groin. Although there is only one sand transportation route before the construction of additional breakwater, new route C has been made after construction of additional breakwater.

However, it seems that the tendency of sand being transported through the route A into the port is weaker and the volume is smaller. Although there is no quantitative evidence, this is because there are several qualitative information as follows: the navigation of fishing boats in the port mouth are secured thanks to excavation by backhoe near the shoreline (the backhoe cannot dredge behind the additional breakwater with its arm), the local people say “the sand deposition decreases in the port after the construction of additional breakwater” in hearing survey, and the decrease of deposition is confirmed behind the additional breakwater by a bottom sounding survey.

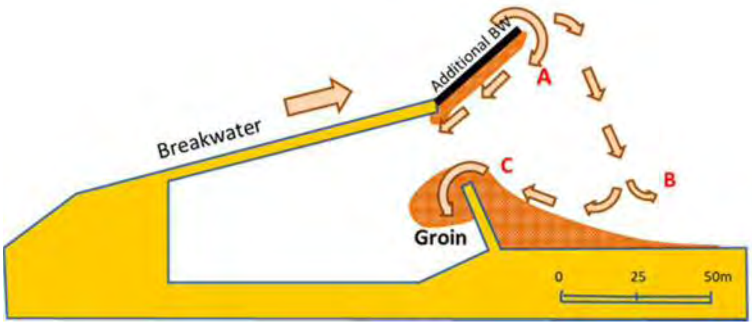


Figure 7-49 Schematic diagram of sand transport after construction of additional breakwater (repost of Figure 7-2)

Figure 7-50 shows the movement of tracers with the facility layout just after the construction of additional breakwater. The tracers injected at point 1 move at a right angle to the shoreline of north beach after passing by the tip of additional breakwater. The tracers injected at point 2 are carried to the direction of groin at high speed and reaches the base of groin. The movement of tracers injected at points 1 and 2 well correspond to the patters of the nearshore currents calculated by numerical simulation, shown in Figure 7-51, under the conditions just after the construction of additional breakwater.

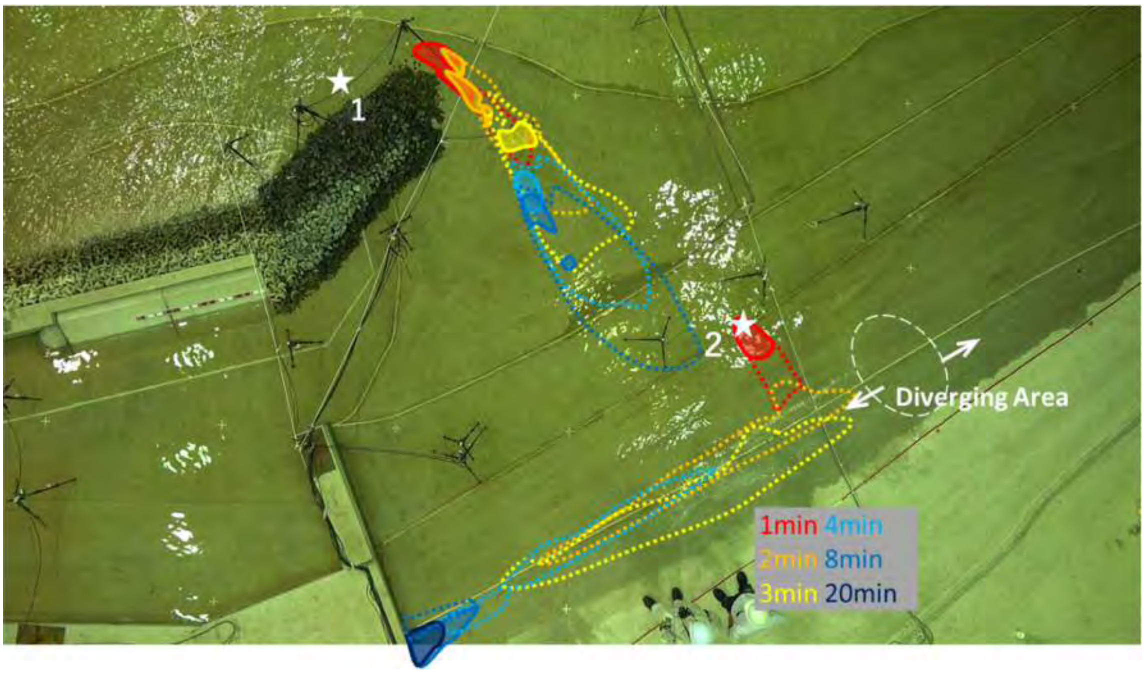


Figure 7-50 Movement of tracers with facility layout just after construction of additional breakwater

In addition, a circle by a dashed line in Figure 7-50 shows the diverging area of nearshore currents confirmed by the movement of dyed water. In comparison with the diverging area shown in Figure 7-44, it is shifted to the north (right) and the shifted length is almost the same as the length of additional breakwater. This location also well corresponds to the diverging area of the nearshore currents calculated by the numerical simulation, Figure 7-51.

It should be noted that the tracers do not come around the tip of breakwater and go into the port. This is judged as a significantly important phenomenon, so the detail reasons are described at the later section for the countermeasures. In any case, this fact does not contradict to the impression after the site survey in Phase 1, that is “smaller amount of sand is transported through route A, Figure 7-49, after the construction of additional breakwater, weakening the tendency that the sand is transported into the port.”

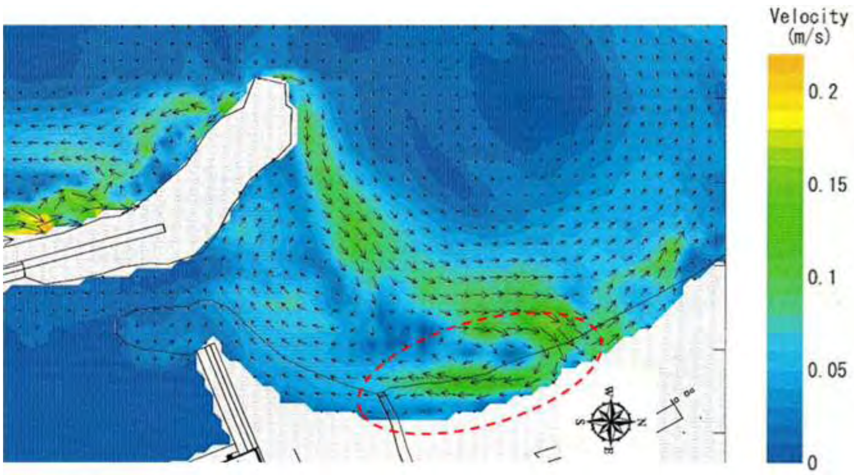


Figure 7-51 Nearshore currents just after construction of additional breakwater
(repost of Figure 7-3)

It is already explained in Figure 7-45 that the deposition occurs where the movement of tracers is stopped. As a result, the sand deposits at the north side beach of the groin and the shoreline is advanced. Therefore, the tracer tracking experiment has been conducted after forming the accreted topography by placing mortar on the model bed.

Figure 7-52 Tracer movement after advancement of shoreline due to construction of additional breakwater

Figure 7-52 shows the movement of tracers after advancement of shoreline at the north side of groin due to the construction of additional breakwater. The movement of tracers injected at point 1 is the same as the situation just after construction of additional breakwater, see Figure 7-50. The tracers injected at point 2 direct to the groin, however, the tracers do not reach the groin. It is considered that the connection part between depositional topography by mortar and original beach topography is sharp and the tracer movement stops at the acute angle part. It was unavoidable to have acute angle part due to the limitation of thickness for placing the mortar. However, since sand deposition occurs at the place where the tracers stop, it can be considered that the shoreline is advanced and this acute part becomes gentler, which enhances the tracer movement toward the tip of groin.

The depositional topography is made up to the tip of groin, and the tracers injected at point 3 are carried to the inside of the port beyond the groin as seen in Figure 7-52. This movement of tracers corresponds to the situation that the sand is getting in the portside of groin after the installation of additional breakwater shown in the Photo 7-13.

Photo 7-13 Situation that sand flows in and deposits passing through tip of groin (13 Aug., 2018)

(3) Concerns to interpret the result of experiment combining the fixed bed model and the tracers

By combining the fixed bed model and the tracers, the reproductions have been attempted for the two typical situations of sand deposition in the fishing port occurred in the past. The prototype sand movement can be examined by tracking tracers in the experiment. However, we have no data related with the prototype sand movement. The data we have is the topographic change formed as a result of sand movement. In other words, the experimental data cannot be compared directly with the prototype data due to the different content. Therefore, the topographic change is assumed from the tracer movement in the experiment and is referred to the prototype. In this case, it is necessary to pay attention that the prototype sand movement is the continuous phenomenon in terms of time.

The tracer injection in the experiment is instantaneous and not continuous in terms of time. Then, the result of tracer movement must be accumulated when the topographic change is inferred from the tracer movements. In concrete terms, it is simple that “the sand deposits and the water depth becomes shallow or the shoreline is advanced at the point where the tracers stop in the experiment of the instantaneous tracer injection". By this consideration, it has been confirmed that the experiment combining the fixed bed model and the tracers can reproduce sand transport phenomenon at the site.

However, what is confirmed in this experiment is only the deposition inside the port and shoreline advancement, while there is no guarantee for the reproducibility of topographic changes such as scouring and erosion. The matter concerning to this problem is described later in a part related with the scouring behind the submerged breakwater.

7.2.3 Function and effect of second sand groin

Figure 7-53 is the repost of Figure 7-52. Figure 7-54 shows the movement of tracers when the second sand groin in constructed. The location, length and other conditions of the second sand groin have been determined by the numerical simulation of shoreline change.

Figure 7-53 Movement of tracers after advancement of the shoreline due to the construction of additional breakwater (repost of Figure 7-52)

Comparing the movement of tracers before, Figure 7-53, and the just after, Figure 7-54, the construction of second groin, most of the tracers injected at point 1 have the same tendency of movements in the both cases. The movements of tracers injected at point 2 is almost the same each other, directing to south after being carried toward the shoreline. The movement of tracers just after the construction of second groin well corresponds to the pattern of nearshore currents calculated by the numerical simulation, Figure 7-55.

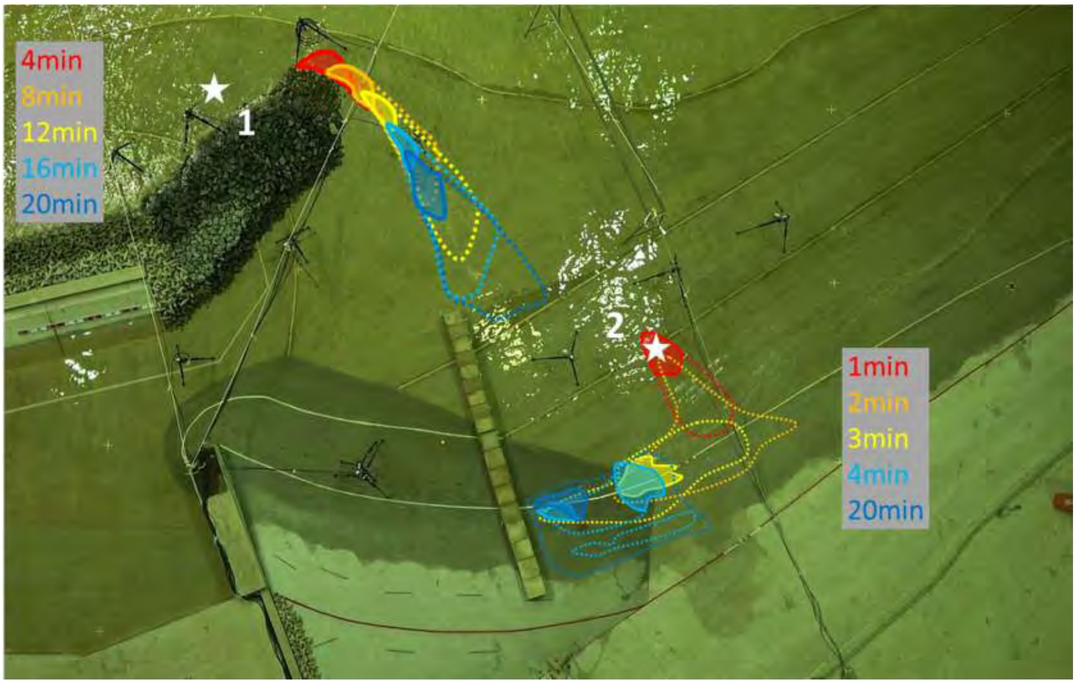


Figure 7-54 Movement of tracers just after installation of second groin

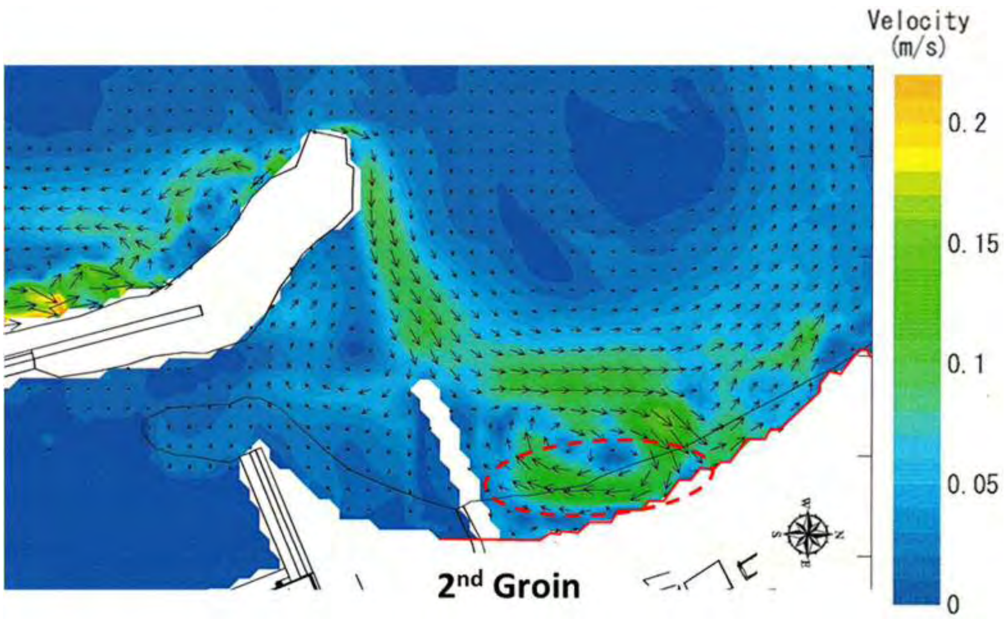


Figure 7-55 Nearshore currents just after construction of second groin (repost of Figure 7-30)

Since tracers come and stay at the north side base of second groin as seen in Figure 7-54, the sand deposits there and advancement of shoreline occurs in the prototype. And so, the tracer tracking experiment has been carried out changing the fixed bed to the situation that the shoreline is advanced. The result is shown in the Figure 7-56.

According to the Figure 7-56, the movement of tracers injected at point 1 is almost the same as that before the shoreline is advanced. On the contrary, the tracers injected at point 2 move to the north direction. Moreover, the tracers have been flowed away in 3 minutes after injection, so the movement speed is fast. In short, the sand movement to the south direction which would cause deposition in the port has disappeared. This movement of tracers well corresponds to the pattern of nearshore currents, Figure 7-57, calculated by the numerical simulation.

From the above, the function of the second groin proved by numerical simulation, that is to say that the second groin prevents the sand causing the port deposition and leads the sand to the north direction have been confirmed also by the hydraulic model experiment.

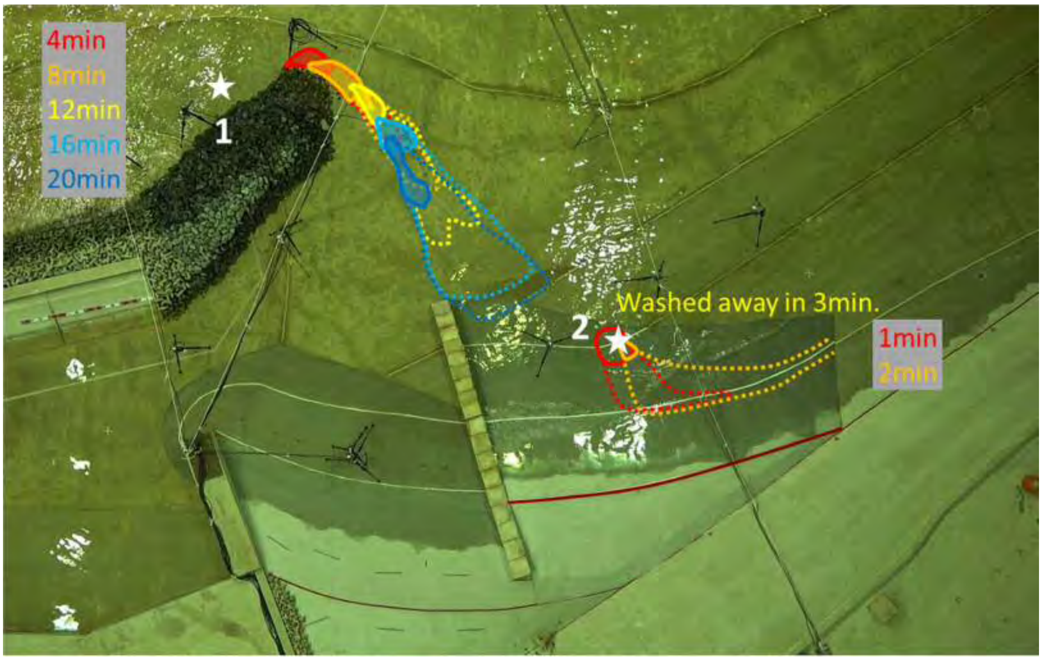


Figure 7-56 Movement of tracers after shoreline advancement

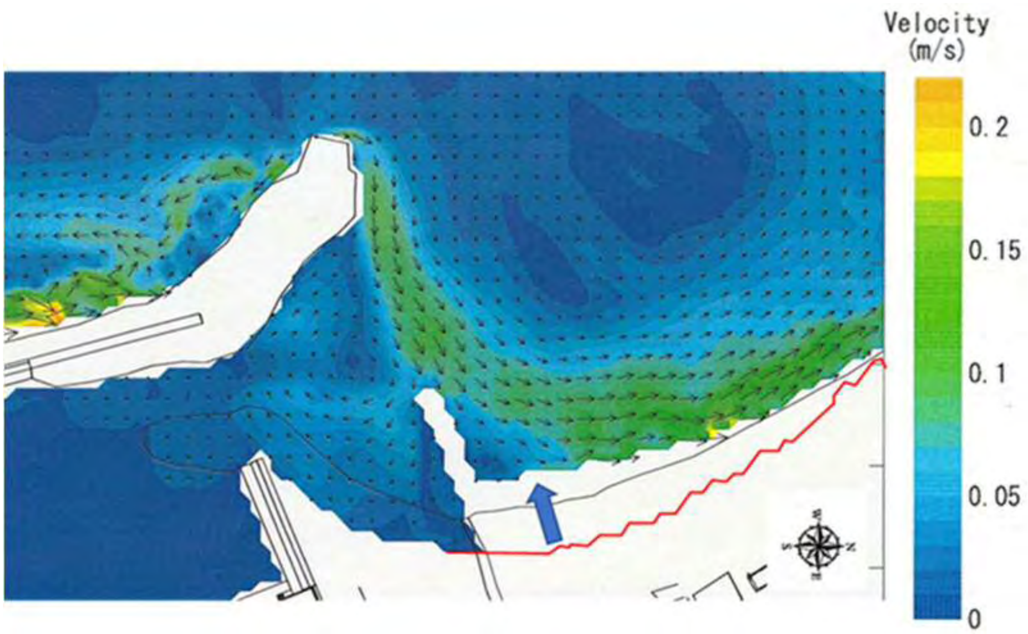


Figure 7-57 Nearshore currents after shoreline advancement (repost of Figure 7-31)

Small drainage ditch for the miscellaneous waste waters flows in around the base of second groin. Slightly changing the location of second groin, the experiment has been conducted to study how to handle this matter. The second groin is turned around its tip, circled in red in the Figure, in a clockwise direction as shown in Figure 7-58. The movement of tracers shown in Figure 7-58 is almost the same as that in Figure 7-54 before turning the second groin. It is considered that the influence due to difference of locations becomes smaller when the shoreline on the north side base of second groin is advanced. Therefore, if the tip of second groin is fixed, it is almost sure that the change of this degree in location never lose its function as the groin.

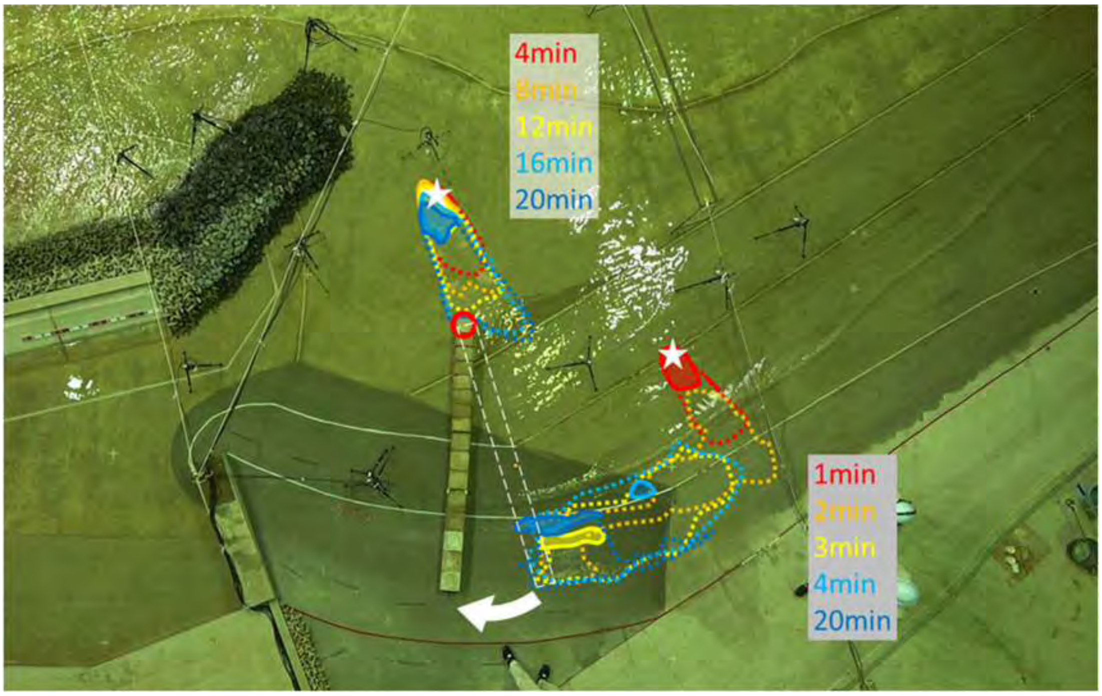


Figure 7-58 Change of installation location of second groin

7.2.4 Hydraulic features and effects of submerged breakwater

In terms of prototype size of submerged breakwater constructed at the tip of additional breakwater, the submerged depth of crown is 0.43 m (-0.2 m crown level, MSL+0.23 m experiment water level), the length is 20 m, and the construction is on the extension of the additional breakwater.

Experiments have been conducted paying attention on the following 3 issues related with the hydraulic features of this submerged breakwater:

- ＊ Wave sheltering function
- ＊ Prevention function of sand wraparound
- ＊ Scouring behind submerged breakwater

In this part, “hydraulic features and effects of submerged breakwater” is explained by taking these results into consideration.

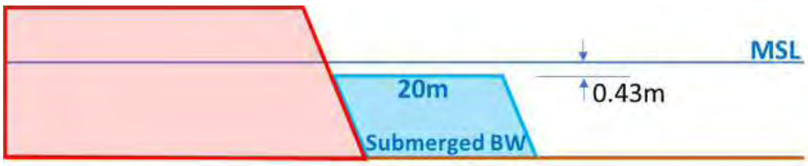
Also, the necessity for impermeability structure of submerged breakwater is mentioned.

(1) Wave sheltering function

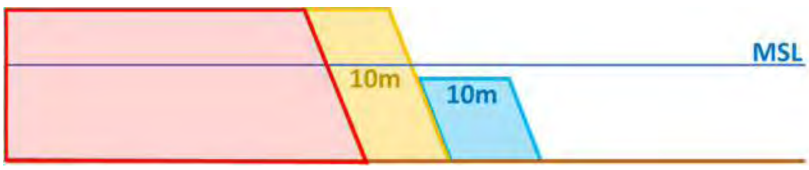
As pointed out in 7.1.3 (1), if the structure constructed on the extension of the additional breakwater has a strong wave sheltering function, the shoreline on the north beach is further advanced. Therefore, it is necessary to check the sheltering function of submerged breakwater.

Figure 7-59 shows the conceptual side-view diagrams of structures, which are combinations of the additional breakwater and the submerged breakwater. These combination patterns are examined by the experiments to confirm their sheltering effects. The red color portion is the existing additional breakwater with the length of 30 m at MSL. The blue color portion is the submerged breakwater. The yellow color portion is the extended structure of additional breakwater and the waves do not overtop its crown. The figure is the length of each facility. The length of submerged breakwater out of newly constructed portion 20 m becomes shorter with (2) 20m, (3) 10m and (4) 0m.

(1) Additional breakwater 30 m (existing)



(2) Additional breakwater 30 m + submerged breakwater 20 m



(3) Additional Breakwater 30 m + extension 10 m + submerged breakwater 10 m

(4) Additional breakwater 30 m + extension 20 m

Figure 7-59 Side-view diagrams of pattern combining additional breakwater and submerged breakwater

Figure 7-60 shows the plan-views of legend, which indicates the combination of additional breakwater and submerged breakwater, and wave measuring points. Wave transmission coefficient has been evaluated by the wave heights measured at the offshore side and landside of submerged breakwater.

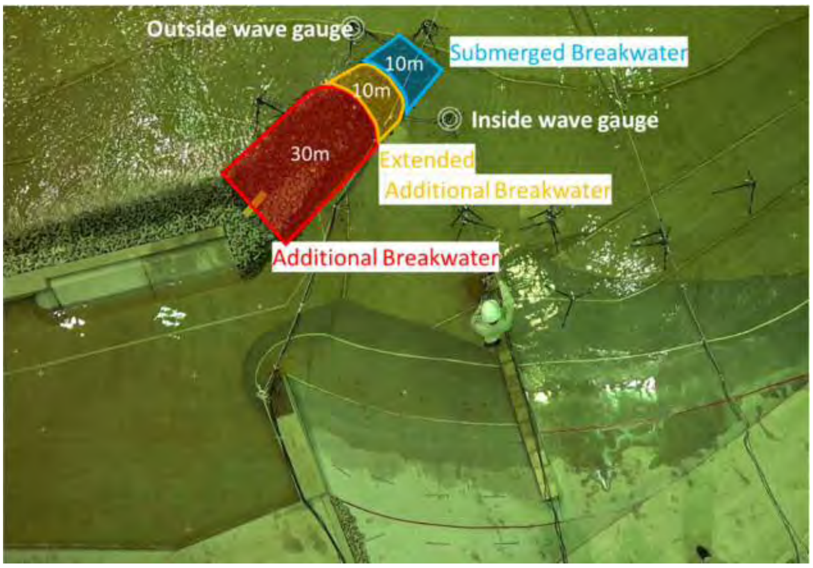
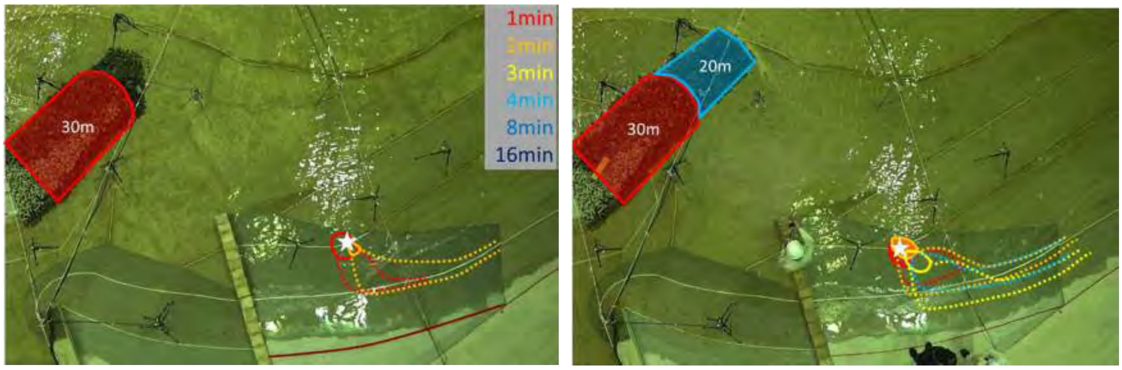
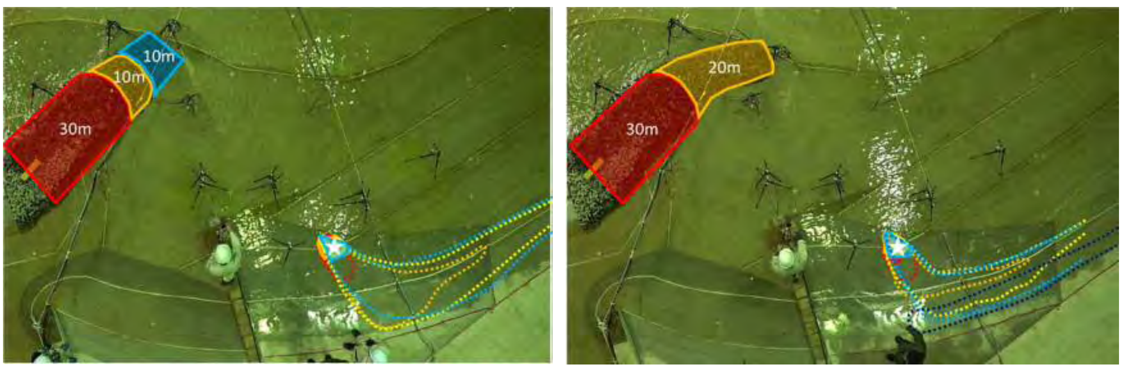


Figure 7-60 Legend of combining additional breakwater and submerged breakwater, and wave measuring points

Figure 7-61 shows the results of tracer tracking by combination pattern. The tracer injection point is the front face of the north side beach of the second groin. Tracers injected in this point are rapidly transported to the north direction (to the right) and flow out to outside of the survey area.



(1) Add. BW 30m (existing) (2) Add. BW 30m + Submerged BW 20 m



(3) Add. BW 30 m + Add. BW extension 10 m + submerged BW 10 m (4) Add. BW 30 m + Add. BW 20 m extension

Figure 7-61 Patterns of submerged breakwater and movement of tracers

Figure 7-62 shows the time until the tracers flow out for each combination pattern of structures installed at the tip of additional breakwater. The times to flow out are 3 minutes for (1) additional BW 30 m (existing), 4 minutes for (2) + submerged BW 20 m, 7 minutes for (3) + additional BW extension 10 m + submerged BW 10 m, and 16 minutes for (4) + additional BW 20 m extension. Compared to the current situation (1), the time to flow out is rather longer in the pattern (4) where the additional breakwater is extended for 20 m. This is because that longshore currents become weak by the extension of additional breakwater. In other words, this is the wave sheltering effect by the extension of additional breakwater. While, in the patterns (2) and (3) where the submerged breakwater is constructed respectively, the time to flow out is slightly prolonged in comparison with pattern (1). With this, it proves that the submerged breakwater has very weak wave sheltering function.

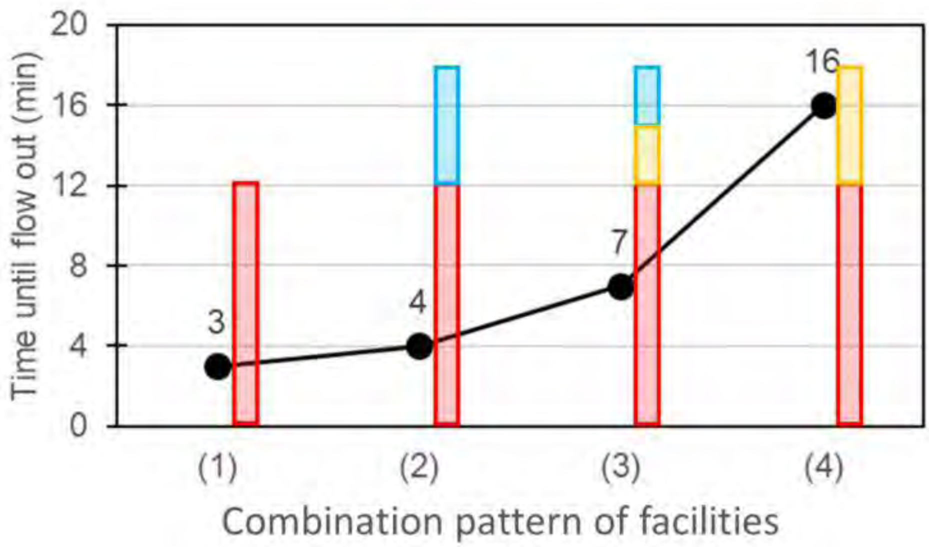


Figure 7-62 Time until the tracers flow out to the outside of survey area

In Figure 7-63, the upper shows the wave heights measured at inside and outside of the structure constructed at the tip of additional breakwater, and the lower shows the wave height transmission coefficient calculated by dividing the wave height inside the port by the wave height outside the port. The inside wave height of (2) + submerged BW 20 m is slightly small in comparison with that of (1) additional breakwater 30 m (existing). On the contrary, in (3) and (4), the inside wave height becomes smaller when the extension length of additional breakwater becomes longer. As to the wave height transmission coefficient, it becomes smaller being 0.58 in (3) and 0.31 for (4) against 0.89 in (2). That is, the sheltering function of submerged breakwater is weak and the impact on sand transport at the north beach is small in comparison with the structure of which the crown height is higher than the water surface.

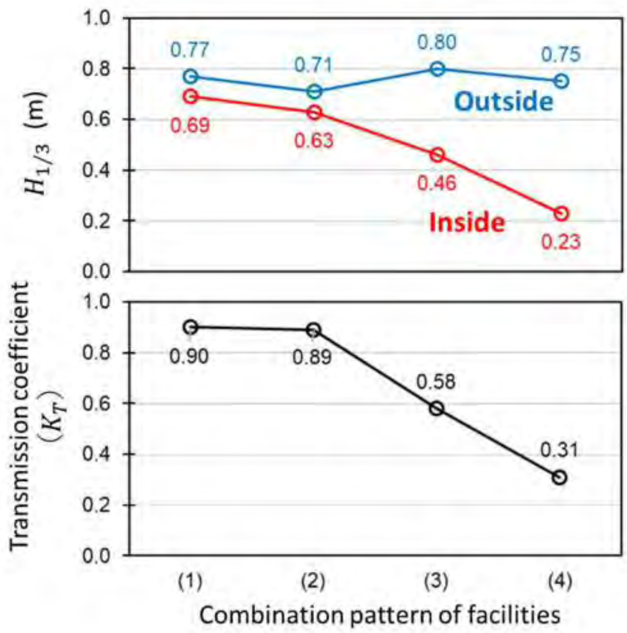
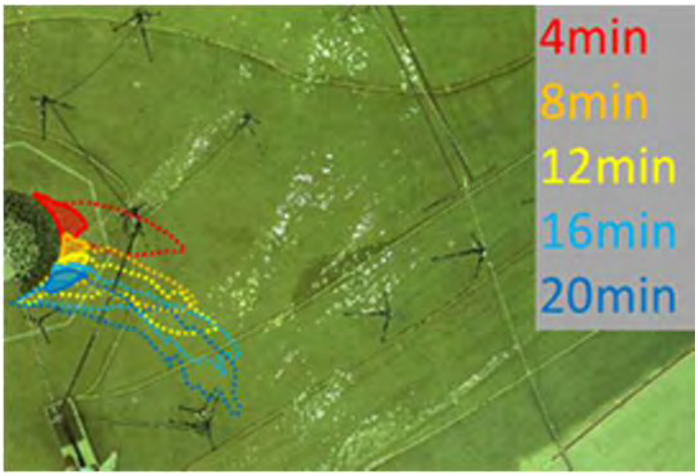


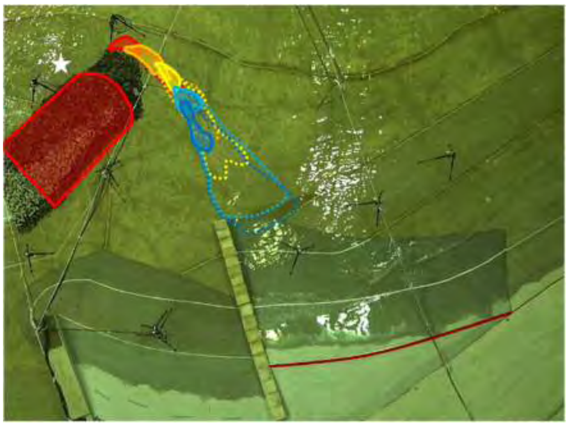
Figure 7-63 Inside and outside wave heights and transmission coefficient of structures (refer to Figure 7-60 for the wave measuring point)

(2) Prevention function of sand wraparound

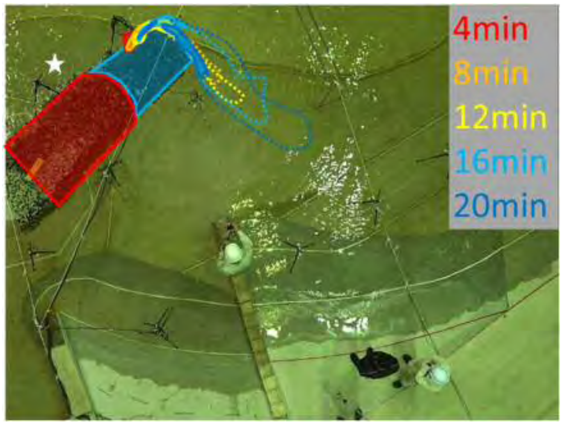
Figure 7-64 shows the movement of tracers by each pattern of combining the structures constructed at the tip of additional breakwater. Injection point of tracers, marked by ☆, is located outside of the port. The combination patterns (1) to (4) correspond to the ones in Figure 7-59 and Figure 7-61. The pattern (0) in Figure 7-64 is the situation before the construction of additional breakwater, which is the same as that at the time of construction completion in Choiseul fishing port.



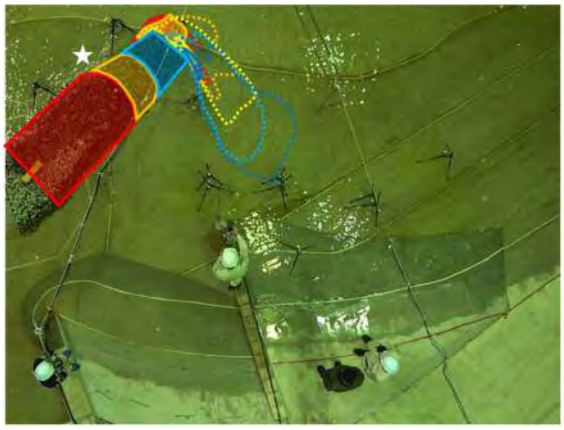
(0) Construction completion (No additional breakwater)



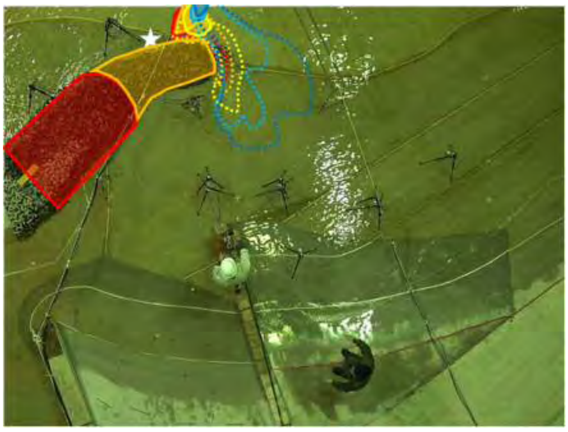
(1) Tip of add. BW (No structure)



(2) Submerged BW 20 m



(3) Add. BW ext.10 m & Submerged BW 10 m



(4) Add. BW 20 m

Figure 7-64 Combination pattern of structures at the tip of breakwater and the movement of tracers

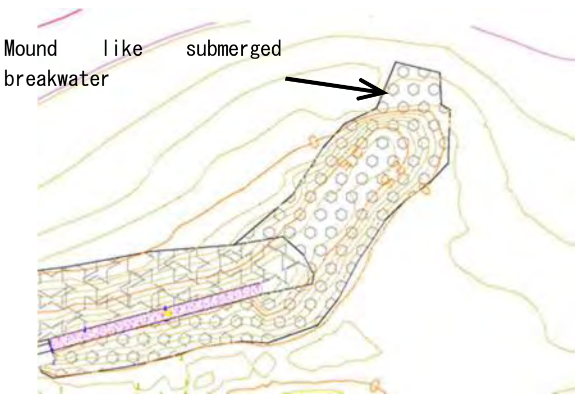
Inspecting the movement of tracers in Figure 7-64, tracers move to the tip of structure from the injection point in any structure combination patterns and curb toward the north beach. After that, movements of tracers can be divided into two groups on the movement direction. One goes toward the north beach, and the other wraps around the tip and changes the direction toward the port mouth. The former is called "no wraparound (No WA)" and the latter is referred to as "wraparound (WA)", and the categorization is listed in Table 7-3 below.

Table 7-3 Combination pattern of structures, existence of wraparound ("No. WA" / "WA") and the relation with the existence of submerged breakwater

		Submerged Breakwater	
		Exist	Not exist
Wraparound	No WA	(1)(2)(3)	
	WA		(0)(4)

Here, the reason why the layout (1) is categorized as "WA" is explained. The pattern (1) is the present additional breakwater. The structure above the sea surface of this additional breakwater has been confirmed by visual observation at the site. However, at that time, the structure under the water could not be comprehended. As a result of the bathymetric survey on November 2017, it has been found that rubble stones are placed for the length of 6 m under the water at the tip of additional breakwater, referring to the left map of Figure 7-65. Hence, this situation is faithfully reproduced using crushed stones in the hydraulic model experiment, which is an area circled by red line in the right photo of Figure 7-65. It is judged that the group of rubble stones has the same hydraulic features as the submerged breakwater.

According to the Table 7-3, in case that submerged breakwater exists at the tip of additional breakwater, tracers do not wrap around. In case that submerged breakwater does not exist, tracers do wraparound. Therefore, the submerged breakwater is expected to have the protection function for the sand wraparound.



Bathymetric map surveyed on November 2017

Additional breakwater in hydraulic model experiment

Figure 7-65 Structure like submerged breakwater at the tip of existing additional breakwater

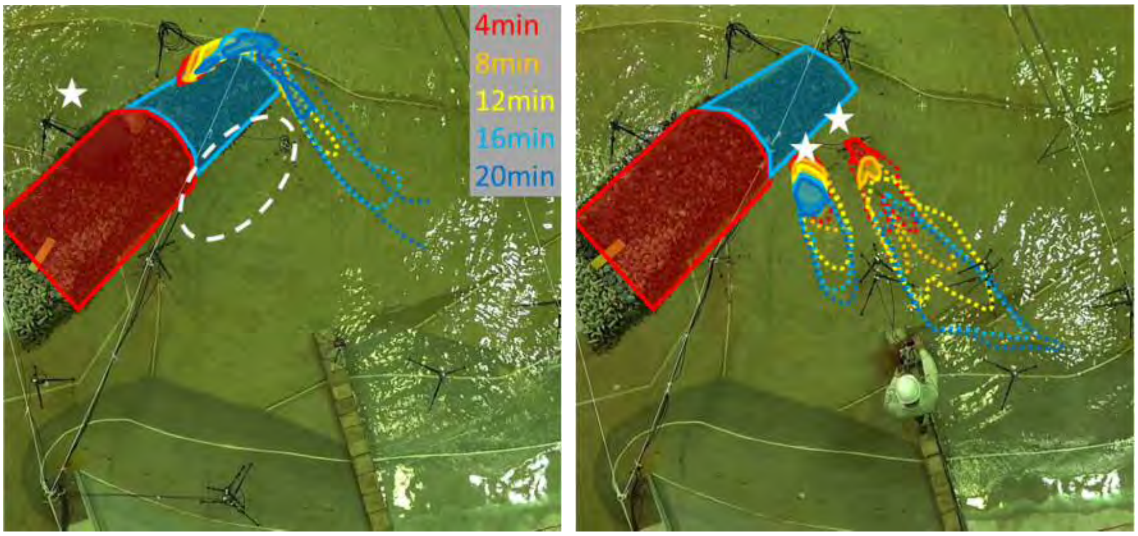
(3) Scouring behind the submerged breakwater

Generally, seabed behind a submerged breakwater is scoured, see Figure 7-36 and 7-37. Although scour must be found if a submerged breakwater is constructed at the tip of additional breakwater in Choiseul fishing port, it is actually impossible to reproduce the phenomenon of scour in the fixed bed model. However, scour can be confirmed by combining results of 2 experiments.

Figure 7-66 shows movement of tracers around submerged breakwater[1)]. In (1), tracers injected outside of the port are firstly carried to the tip of additional breakwater, and then, to the north beach. This implies that sand is not supplied from outside of the port to the area circled by a white dashed line. In Figure 7-66 (2), tracers injected into 2 points behind the submerged breakwater are transported toward the land with almost perpendicular angle to the submerged breakwater. Combining the results of Figure 7-66 (1) and (2), sand is not carried to the area circled by a white dashed line from offshore, but sand originally existed in this area is carried toward the land. Therefore, outflow occurs without sand supply behind the submerged breakwater, resultantly the seabed is inferred to be scoured.

【Reference】

[1)] The submerged breakwater is 20 m long. In this experiment, existing projecting part of the submerged breakwater is slightly eliminated (figure 7-65), and the offshore side was shaped to be gentle configuration.



(1) Injection of tracers outside of port

(2) Injection of tracers behind submerged breakwater

Figure 7-66 Movement of tracers around submerged breakwater of 20 m long

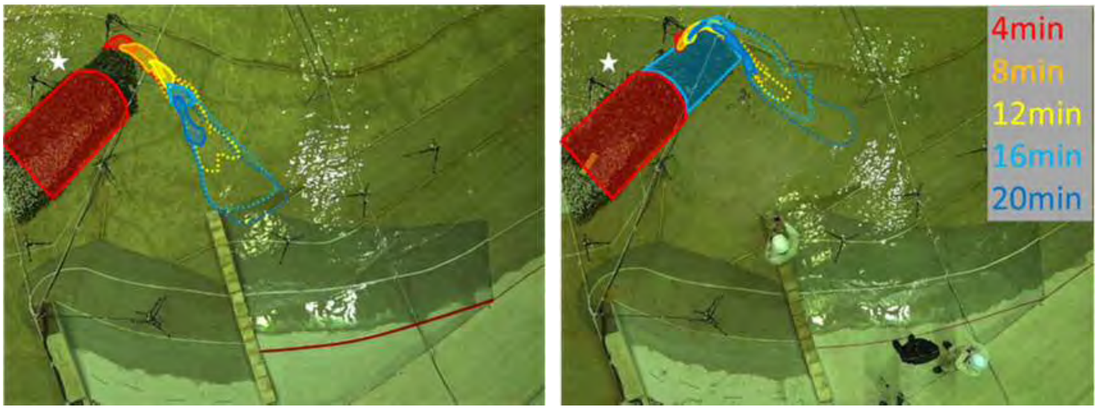
(4) Functions and effects of submerged breakwater

According to the results of experiments by combination of fixed bed model and tracers, functions and effects of submerged breakwater (20m) constructed at the tip of additional breakwater are summarized as follows.

a. Sheltering effect of submerged breakwater is weak since the crown is underwater and the majority of wave energy can pass over. Impacts of submerged breakwater on northward nearshore currents on north beach is extremely small, so sand transport to the port entrance (southward) does not occur.

b. The sand, being transported through offshore side of the breakwater to the tip of submerged breakwater, turns to the right angle which is normal to the submerged breakwater, and is carried to the north beach. In other words, the submerged breakwater can prevent sand from wrapping around the tip and going to the port entrance. It is inferred that effect of landward currents generated above the submerged breakwater reaches to its back side, which prevents wraparound movement of sand.

c. Existing additional breakwater has a projecting mound made with riprap at the underwater tip, refer to Figure 7-65, which has a similar function to the submerged breakwater of preventing wraparound of sand. However, according to Figure 7-67 (1), northward sand arrives near the tip of second groin. Depending on the conditions, it is possible that sand deposits on south side (left side) of the second groin. The sand should deposit farther northward away from the second groin. Referring to Figure 7-67 (2), if the submerged breakwater of 20m long is constructed, the sand finally arrives at farther point from the second groin after changing the moving direction at the tip of submerged breakwater. Then, the sand is carried in the north (to the right side) direction by northward nearshore currents.



(1) Without facility at the tip of additional breakwater

(2) Construction of submerged breakwater (20 m)

Figure 7-67 Repost of Figure 7-64 (1) and (2)

d. At the back side of submerged breakwater circled by a white dashed line in Figure 7-68, seabed is scoured without sand deposition, which has a very significant meaning as explained by utilizing Figure 7-69. Figure 7-69 shows the process of deposition based on the data obtained by surveying. Deposition at inner side of the tip of breakwater triggers deposition inside the port basin. The deposition topography gradually develops toward the interior of the port with time. In the case that the submerged breakwater is constructed, seabed behind the submerged breakwater, where a trigger deposition occurs without submerged breakwater, is scoured. Therefore, the deposition topography does not develop to be larger inside the port.

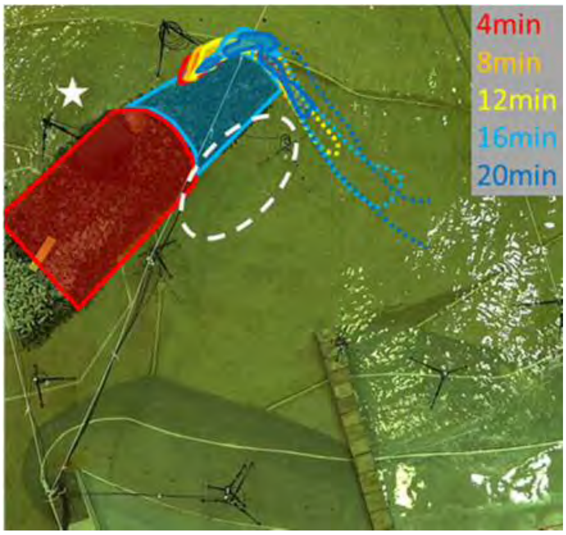


Figure 7-68 Scouring behind the submerged breakwater (partial repost from Figure 7-66)

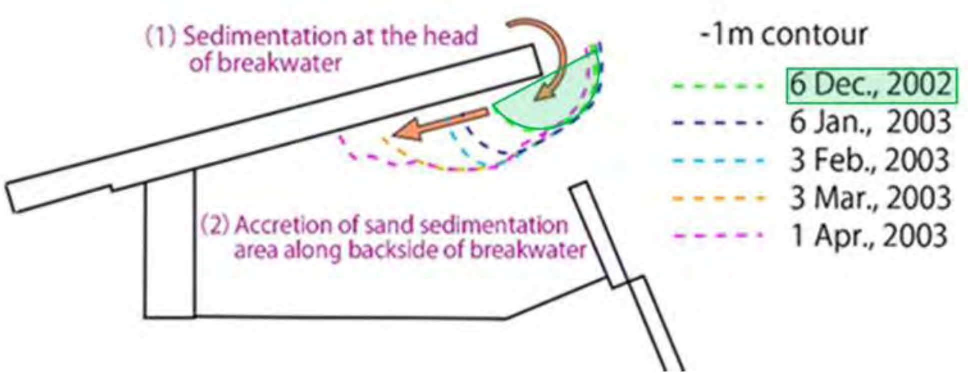


Figure 7-69 Process of deposition inside the port (partial repost from Figure 6-23)

(5) Impermeable structure of submerged breakwater

Wave generation period is 30 minutes in each experiment. Tracers are injected in just 10 minutes after the commencement of wave generation, and movement of tracers is tracked for 20 minutes. After the experiment, slight deposition of tracers is confirmed in the area A in Figure 7-70. There is a doubt about which route the tracers take, since all tracers have been removed after each experiment from the basin. Examining Figure 7-70, the area A where tracers slightly deposited is not connected with the area B. Therefore, tracers which finally deposit in the area Ado not pass through the route going around the tip of submerged breakwater.

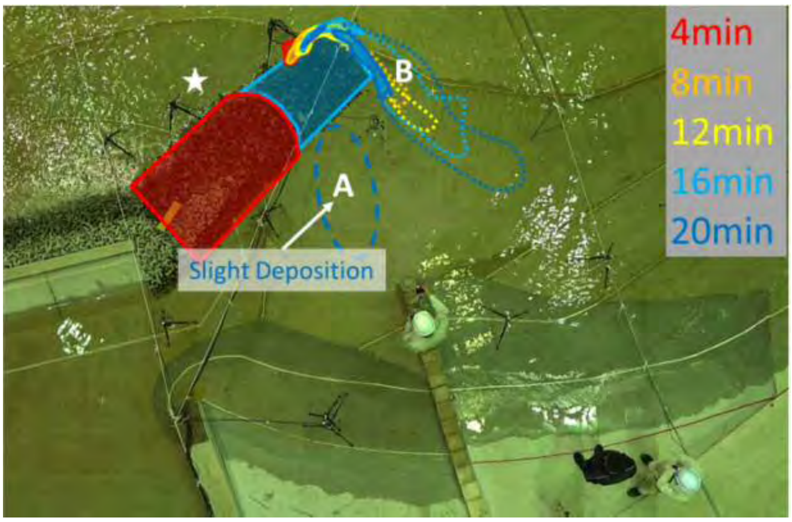
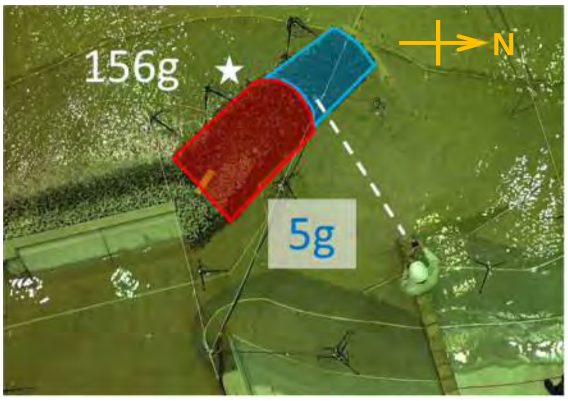


Figure 7-70 Slight deposition behind submerged breakwater (area A)

Figure 7-71 shows the weight of tracers which deposit inside the port and collected after the experiment. Here, the definition of "inside the port" is an area which is the northern side (left side) of a white dashed line connecting the existing additional breakwater and second groin. The weight of tracers injected outside of the port is 156g in each case. On the contrary, length of submerged breakwater is different: (1) submerged breakwater of 20m long, and (2) submerged breakwater of 10m long. If tracers are suspended and transported beyond the submerged breakwater, the weight of tracers deposited inside the port must be proportional to the length of submerged breakwater. However, 5 g and 6 g of tracers are collected respectively so the weight are almost the same. From this fact, it is judged that tracers are not transported beyond the submerged breakwater in suspension.

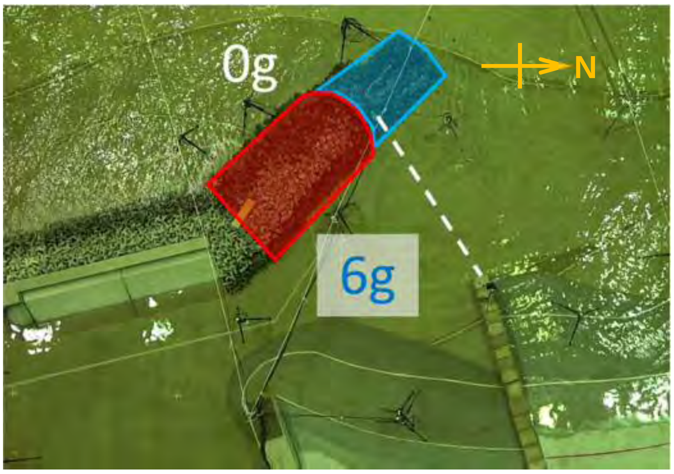
Figure 7-72 shows the weight of collected tracers after generating waves for 30 minutes without injection of tracers. Before starting the experiment, all tracers have been removed from the bed. Weight of collected tracers is 6g which is almost the same as previous experiments. This fact also clearly denies the possibility that tracers are transported beyond the submerged breakwater in suspension.



(1) Submerged breakwater of 20 m long

(2) Additional breakwater of 10 m long and submerged breakwater of 10 m long

Figure 7-71 Weight of tracers deposited inside the port



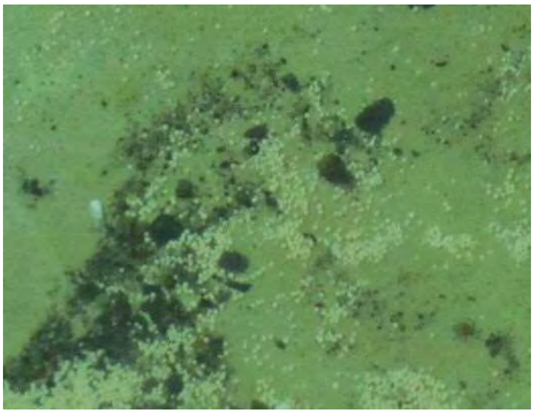
(1) Submerged breakwater of 20 m long

Figure 7-72 Weight of collected tracers inside the port without injection of tracers

Photo 7-14 (1) shows the removal works of stones to confirm the conditions under the submerged breakwater after the execution of experiment with the tracers injected outside of the port. In Photo 7-14 (2), an existence of tracers is confirmed on the bed after removal of stones. From this fact, it is concluded that tracers have passed under the submerged breakwater in the previous experiment, and such tracers come out and are found inside the port in Figure 7-72.

It is necessary to make the submerged breakwater having the structure that sand does not pass through.

(1) removal works of submerged breakwater



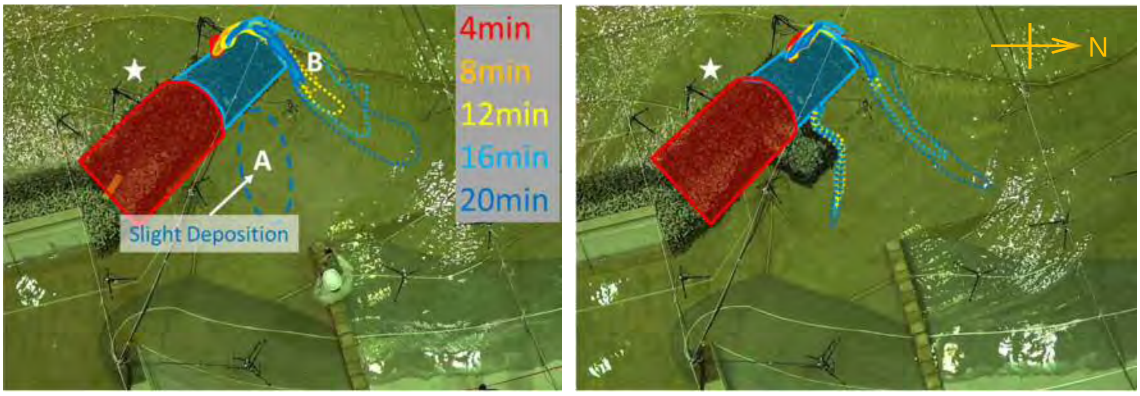
(2) after removal of submerged breakwater

Photo 7-14 Tracers found under the submerged breakwater

7.2.5 Inner Breakwater

Figure 7-73 shows the comparison of tracer movements depending on the existence of inner breakwater under the condition of 20m submerged breakwater. The inner breakwater is constructed with the length of 15.6 m at a right angle to the additional breakwater. Tracer injection point is the outside of the additional breakwater. Tracers passing the tip of submerged breakwater move toward the northern beach of the second groin regardless of the existence of inner breakwater. The tracers pass through the submerged breakwater regardless of the existence of inner breakwater, which move toward inside of the port even if the inner breakwater is constructed. Therefore, function to prevent the sand movement to inside the port is not expected for the inner breakwater.

Fundamentally, the construction of inner breakwater is not necessary since the sand supply to the area behind the submerged breakwater vanishes away if the impermeable submerged breakwater is constructed.



(1) Submerged breakwater 20 m　　(2) Submerged breakwater 20 m ＋ Inner breakwater

Figure 7-73　Comparison of tracer movement depending on the existence of inner breakwater

7.2.6 Weight of collected tracers

In a model experiment on topographic changes due to sediment transport, natural conditions such as waves and tide levels are simplified, and there are side walls of wave basin which do not actually exist in the field. The biggest problem is that the similarity law for sediment transport has not been established. Therefore, it is impossible to quantitatively interpret and examine the numerical data such as amount of sediment transport, topographic change, deposition, etc. obtained from experiments.

In the fixed bed model experiment using tracers, tracers are collected and its weight is measured after each experiment. The measured weight is quantitative amount of the transported tracers. By comparing the weight of injected tracers at the beginning and the measured weight after the experiment, a ratio of transported tracers is obtained. Although a specific numerical value of ratio is obtained, it does not mean quantitative data acquisition. Therefore, it should be noted that results of weight measurement of collected tracers are qualitatively interpreted.

(1) Deposition amount in the port without additional breakwater

Figure 7-74 shows distributions of tracers every four minutes after injection. Tracers collectively deposit in the areas filled with a color. As explained in 7.2.2 (1), it is assumed that tracers in these colored areas are gradually transported towards inside the port.

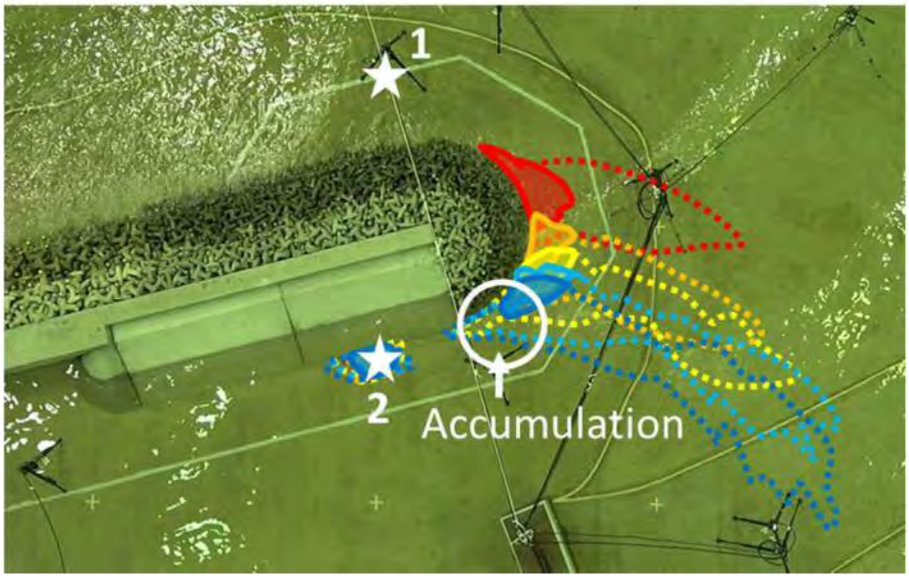


Figure 7-74 Movement of tracers (repost of Figure 7-45)

Weights of tracers collected from the model bed after experiment are shown in Figure 7-75. The area enclosed by a blue line is an area of tracers distributed when the experiment has finished after 20 minutes action of waves. Tracers are separately collected from 3 areas divided by red dashed lines. The area from which 56 g of tracers are collected corresponds to the area filled with a color in Figure 7-74. At the beginning, 156 g of tracers are injected in a point indicated by a white asterisk. It means 36% of injected tracers are transported up to this area. Tracers in the area are gradually transported into the fishing port, in other words, 36% out of the northward longshore sediments along the breakwater is transported into the fishing port.

Figure 7-75 Weight distribution of collected tracers
(without additional breakwater, corresponding to Figure 7-44)

Figure 7-76 indicates the sand budget around the Choiseul fishing port inferred from the result of site data analyses. The median values of these sediment transport amount are used for the shoreline change simulation explained in 7.1.2 (refer to Figure 7-14). Here, the median values are also used. The median value of sediment which deposits inside the port, 2,750 m^3/year, is 34% out of 8,000 m^3/year which is the median value of northward longshore sediment volume along the breakwater. The experimental result of ratio, 36%, is close to this ratio.

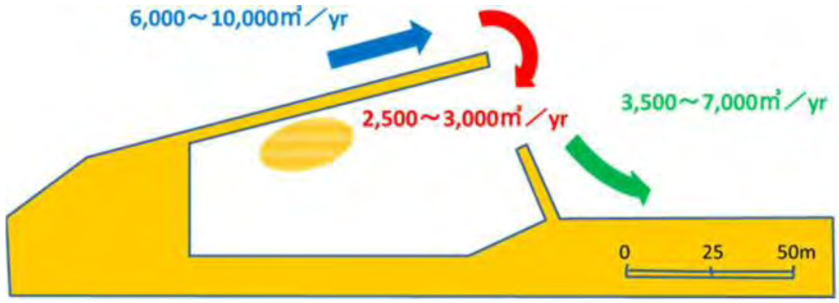


Figure 7-76 Sand budget around Choiseul fishing port (repost of Figure 6-24)

(2) Deposition amount after construction of additional breakwater

Figure 7-77 shows the result of experiment carried out under the condition that the shoreline at the base of groin has been advanced after construction of the additional breakwater. Tracers are injected at two points. Weights of tracers are 156g and 168g at points 1 and 2, respectively. The weight of collected tracers is 147g from the area behind the additional breakwater, which corresponds to 94% of total injected amount. It can be easily inferred that these tracers are transported towards the groin by referring to movement of tracers injected in point 2. Ninety-six percent, 96%(161g), of tracers injected at point 2 move towards the groin. In multiplying these two ratios, it is estimated that 90% of tracers injected at outside of the additional breakwater are transported to near the groin.

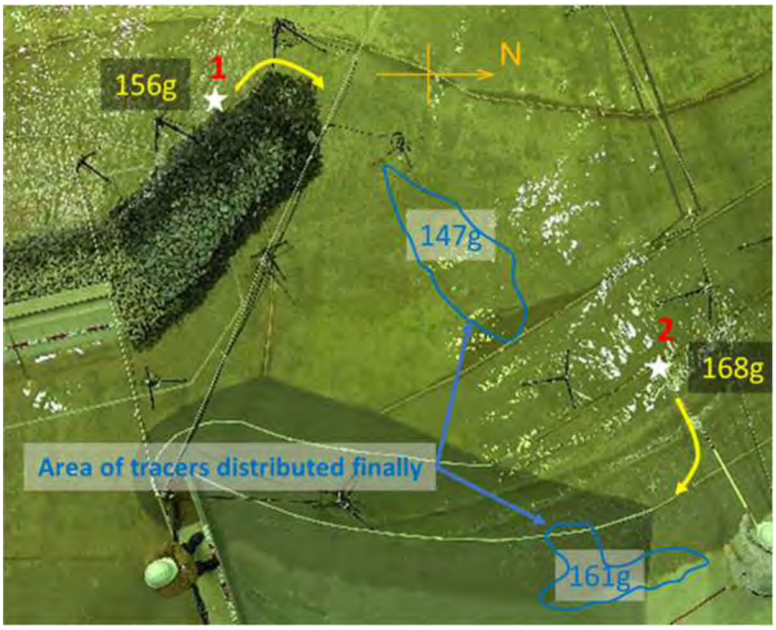
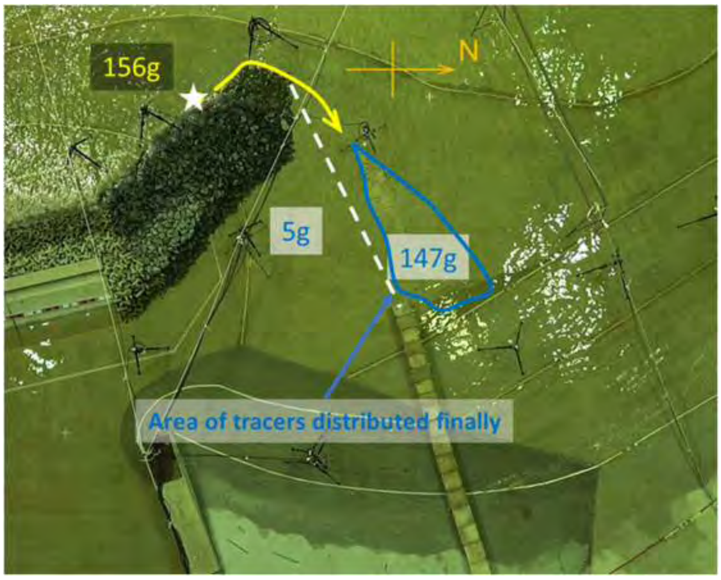


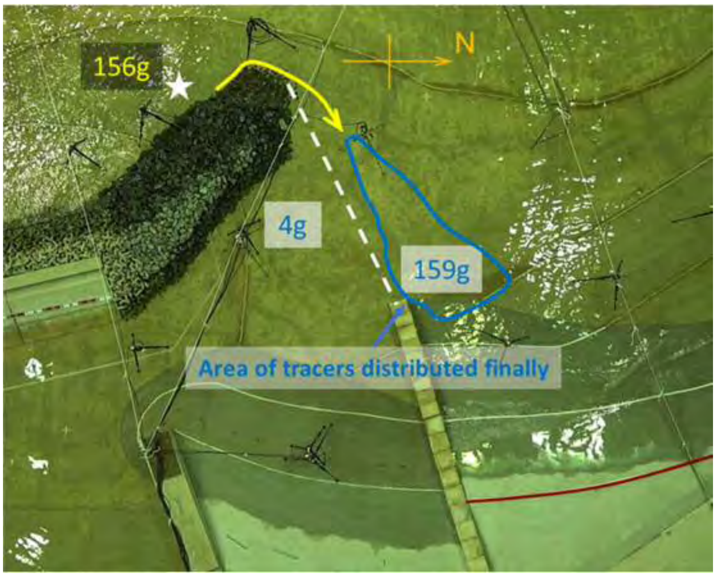
Figure 7-77 Weight distribution of collected tracers
(with additional breakwater, corresponding to Figure 7-52)

(3) Deposition amount after construction of countermeasure facilities

Figure 7-78 shows the experimental results after construction of the second groin. The upper (1) is the case that the second groin has been just constructed, and the lower (2) is the case that the shoreline has been advanced on the north side of the second groin. Results of these two cases are similar each other. Tracers injected outside of the additional breakwater wrap around the additional breakwater and move towards the second groin. The distribution areas of tracers after experiments are northern side of a white dashed line connecting the tips of additional breakwater and second groin. As the more time passes, tracers are expected to reach the north side of the second groin. These amounts are 147 g and 159 g, which are 94% and 102% of injected tracers. Therefore, most of the longshore sediment in front of the Choiseul fishing port from the south to north are not transported into the port.



(1) Just after construction of second groin, corresponding to Figure 7-54



(2) Second groin and advancement of shoreline, corresponding to Figure 7-56

Figure 7-78 Weight distribution of collected tracers (with second groin)

Figure 7-79 shows the results of experiments after construction of second groin and submerged breakwater of 20 m long. Both the upper (1) and lower (2) have the submerged breakwater of 20 m, but the shape on offshore side is slightly different (see【Reference】in 7.2.4.(3)). Tracers are collected from four areas divided as follows.

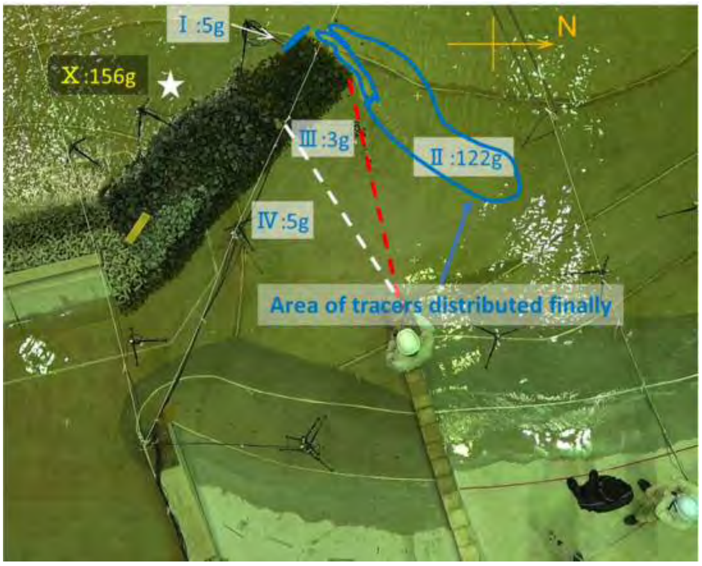
Area I outside of submerged breakwater

Area II north side of a red dashed line connecting the tips of submerged breakwater and second groin

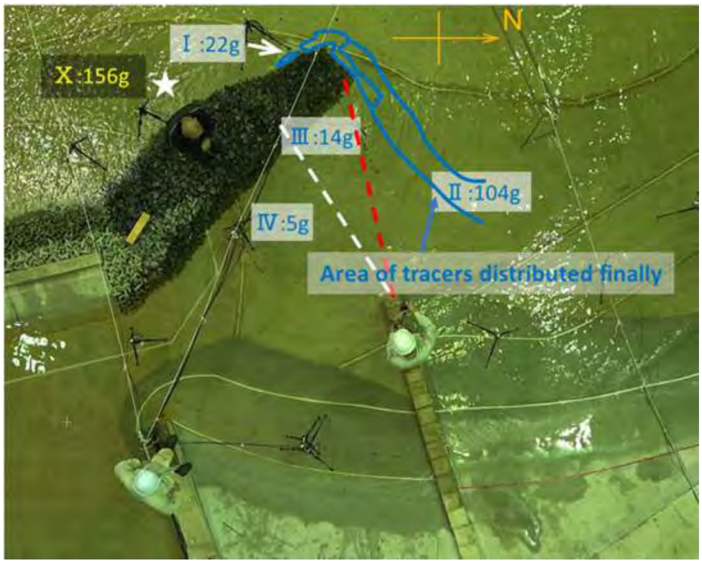
Area III between a white dashed line connecting the tips of additional breakwater and the red dashed line

Area IV near side to the port from the white dashed line

Weights of tracers collected from each area, indicated in Figure 7-79 (1) and (2), are summarized in Table 7-4. The "X" in this table means the weight of injected tracers.



(1) Submerged breakwater of 20 m, corresponding to Figure 7-64 (2)



(2) Submerged breakwater of 20 m with outside gentle slope, corresponding to Figure 7-66 (1)

Figure 7-79 Weight distribution of collected tracers (with second groin + submerged breakwater of 20 m)

Table 7-4 Weights of injected tracers and collected tracers in each area (Unit: g)

	X	I	II	III	IV
Fig.7-79(1)	156	5	122	3	5
Fig.7-79(2)	156	22	104	14	5

Based on Table 7-4, calculation is made to obtain the ratio of tracers which do not go into the fishing port but move towards the north beach, hereinafter this ratio is referred as passing ratio. Results are listed in Table 7-5. Each column means as followings.

First column (a=X-I)	I: Tracer amount remaining outside the submerged breakwater. X: Amount of injected tracer. a (=X-I): Tracer amount which has passed by the tip of submerged breakwater to the lee side.
Second column (b=II+III)	To compare with the result before the construction of submerged breakwater (Figure 7-78), tracer amount, b, on the north side of a white dashed line is regarded as passing one.
Third column (b/a)	This is passing ratio, which is calculated the same as the case before construction of submerged breakwater (Figure 7-78). Calculated passing ratios are 83% and 88%, respectively.
Fourth column (c=X-(I+II+III+IV))	Total collected amount from all areas is less than X of injected amount. This shortage amount, c, is assumingly because tracers are transported to northwards and widely dispersed and it is impossible to collect them.
Fifth column (d=b+c)	Thus, the sum of b and c is considered the total tracers which has passed to the north beach.
Sixth column (d/a)	These are the real passing ratio., The ratios are 97% and 96%, respectively.

Table 7-5 Passing ratio of tracers

	a=X-I	b=II+III	b/a	c=X-(I+II+III+IV)	d=b+c	d/a
Fig.7-79(1)	151	125	0.83	21	146	0.97
Fig.7-79(2)	134	118	0.88	11	129	0.96

(4) Comparison of deposition amount (ratio)

In Table 7-6, deposition ratios estimated in above (1) to (3) are compared. Deposition ratios on the third and fourth rows are the differences between 100% and passing ratio, that is 100% minus passing ratio(%). It should be noted again that these values are qualitative even though numeric comparison is possible.

According to the table, it is expected that “second groin” and “second groin + submerged breakwater 20 m” are effective for preventing deposition in the fishing port. However, the latter has an effect which is not numerically explained. In focusing on distribution areas of tracers in Figure 7-78 and Figure 7-79, the tracers are distributed near the second groin in the former (Figure 7-78), while distribution area moves northwards approximately 20 m, the same length with submerged breakwater, in the latter (Figure 7-79). Therefore, deposition is more unlikely to occur in the latter.

Table 7-6 Comparison of deposition ratio

	Passing ratio (%)	Deposition ratio (%)
Without additional breakwater	—	36
With additional breakwater	—	90
Second groin	98	2
Second groin + submerged breakwater 20 m	97	3

7.3 Study on function and effect of countermeasure by numerical simulation

7.3.1 Calculation condition and reproduction calculation of hydraulic model experiment

(1) Calculation condition

As the accuracy of numerical simulation model on the waves and currents is improved by executing the reproduction of the results of fixed bed hydraulic model experiment, the same calculation conditions are set as the hydraulic model experiment:

Significant wave height; 0.82 m,
Significant wave period; 6.99 s,
Wave direction; S,
Tide level; Mean tide level (= ＋0.23 m)
Crown height level of submerged breakwater; -0.2 m.

The simulation model is based on the energy balance equation in which a diffraction term is also introduced.

The reproduction calculation has been performed on the (2) present situation of topography and (3) second sand groin + submerged breakwater 20 m.

(2) Reproduction of wave heights and nearshore currents for the present situation of topography, corresponding to the experiment shown in Figure 7-52

【Reproducibility of wave height】

Figure 7-80 shows the result of calculation on wave heights and wave directions, and the locations of wave gauges in the model experiment. Figure 7-81 shows the comparison of wave heights measured in the experiment and estimated by the calculation. Figure 7-82 shows the correlation of these two kinds of wave heights. As to the wave heights, it is confirmed that the experimental result is accurately reproduced by the calculation.

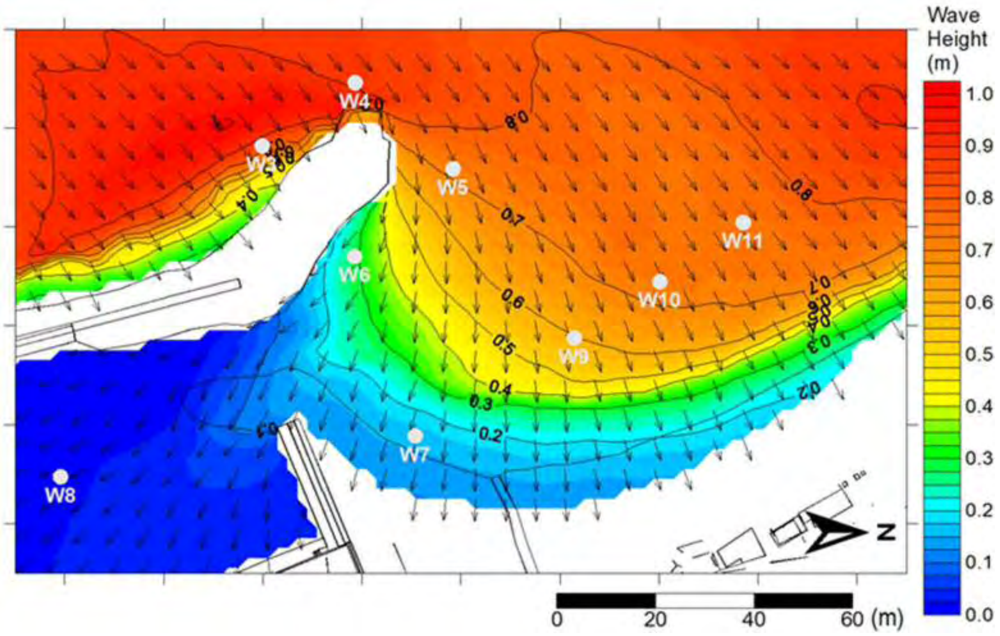


Figure 7-80 Result of calculation on wave deformation, and locations of wave gauges in experiment, present situation of topography

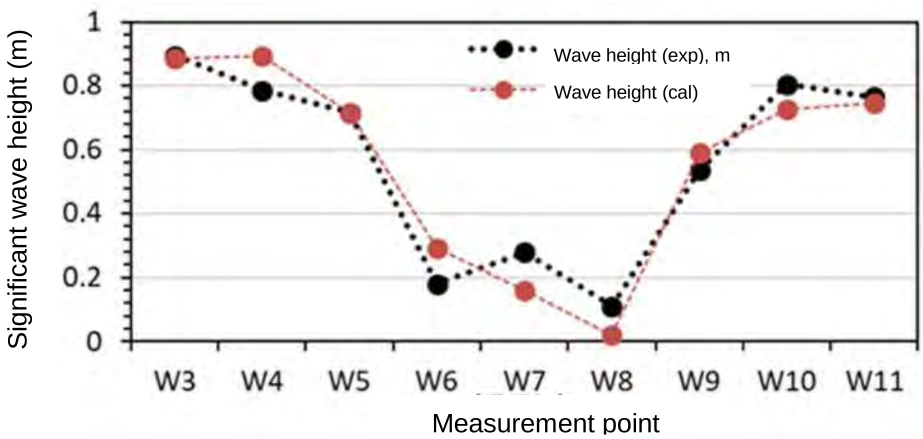


Figure 7-81 Comparison of experimental results and calculated ones of wave height, present situation of topography

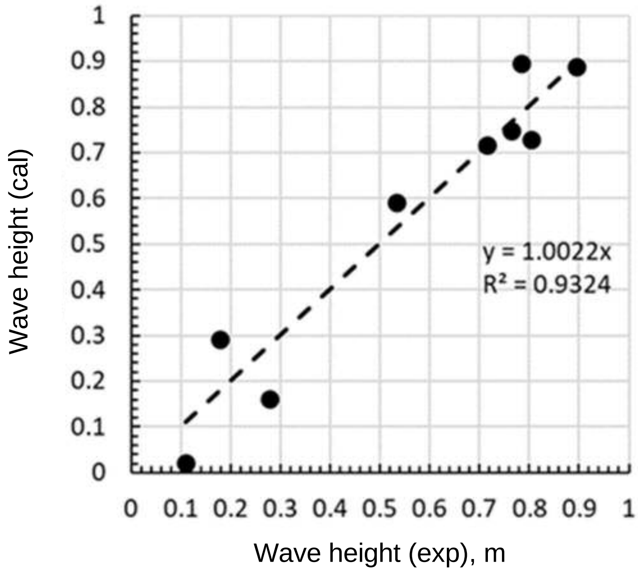


Figure 7-82 Correlation of wave heights of experiment and calculated ones,
present situation of topography

【Reproducibility of nearshore currents】

Figure 7-83 shows the result of calculation on nearshore currents, and the locations of current meters. Figure 7-84 shows the comparison of nearshore currents measured in the experiment and estimated by the calculation. Figure 7-85 shows the correlation of these two kinds of nearshore currents. As to the nearshore current velocities, it is confirmed that the experimental result is accurately reproduced by the calculation.

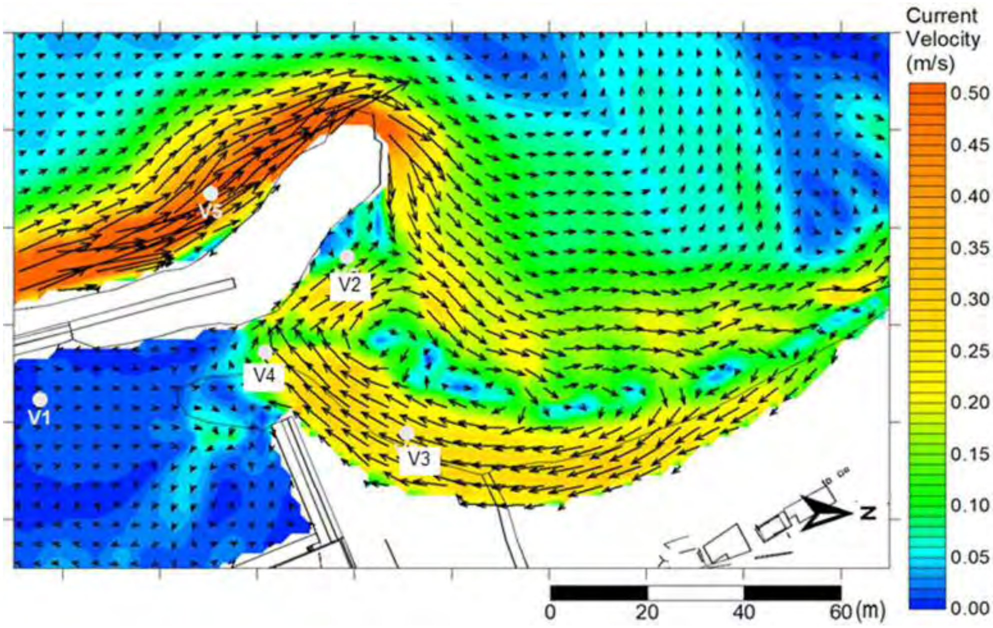


Figure 7-83Result of calculation on nearshore currents, and locations of current meters in experiment,
present situation of topography

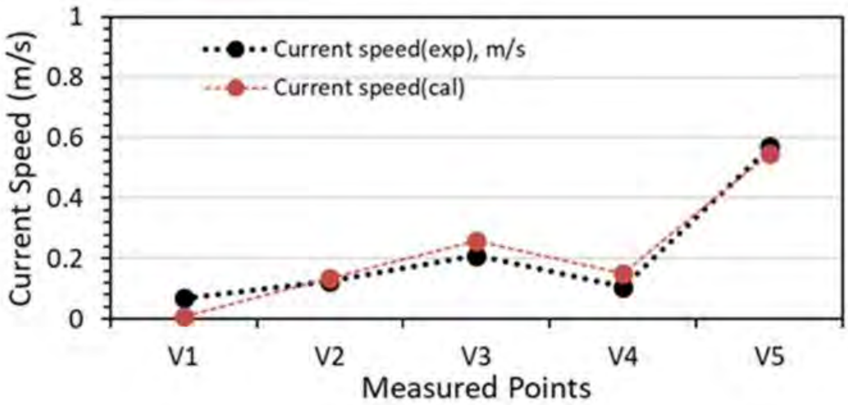


Figure 7-84 Comparison of experimental results and calculated ones of nearshore currents, present situation of topography

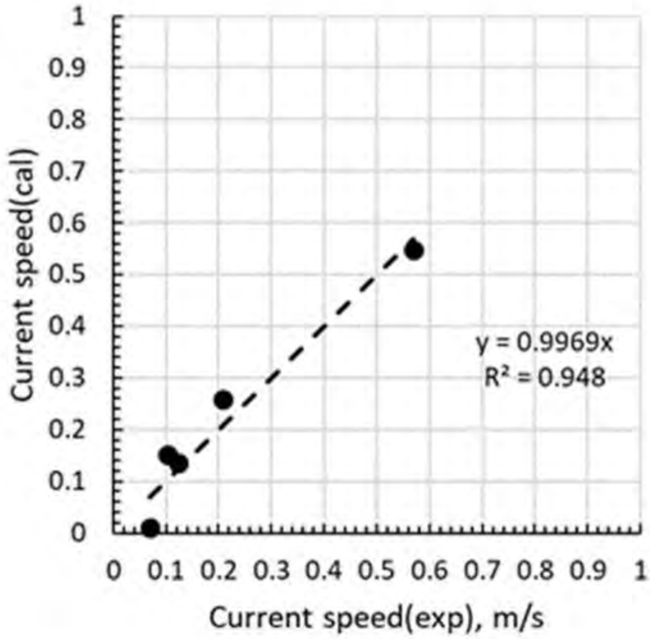


Figure 7-85 Correlation of current speeds in experiment and calculated ones, present situation of topography

(3) Reproduction of wave heights and nearshore currents in the condition of second sand groin + submerged breakwater 20 m, corresponding to Figure 7-61 (2) and Figure 7-64 (2)

【Reproducibility of wave heights】

Figure 7-86 shows the result of calculation on wave heights and nearshore currents, and the locations of wave gauges in the model experiment. Figure 7-87 shows comparison of the wave heights measured in the experiment and estimated by the calculation. Figure 7-88 shows correlation of these two kinds of wave height. Referring to these figures, it is confirmed that experimental results at the points W5, W9, W10 and W11 behind the submerged breakwater are accurately reproduced by the calculation.

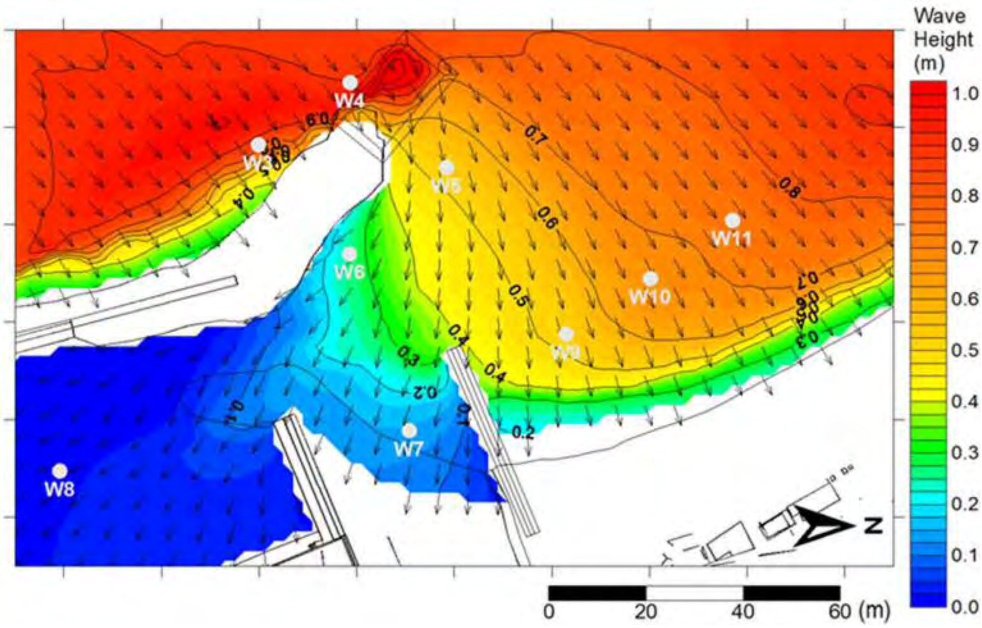


Figure 7-86 Result of calculation on wave deformation, and locations of wave gauges in experiment for the case of second groin + submerged breakwater 20 m

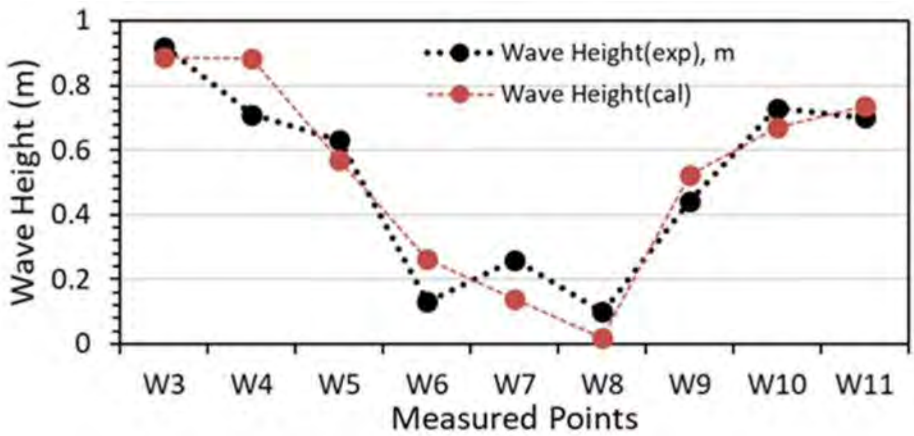


Figure 7-87 Comparison of experimental wave heights and calculated ones, second groin + submerged breakwater 20 m

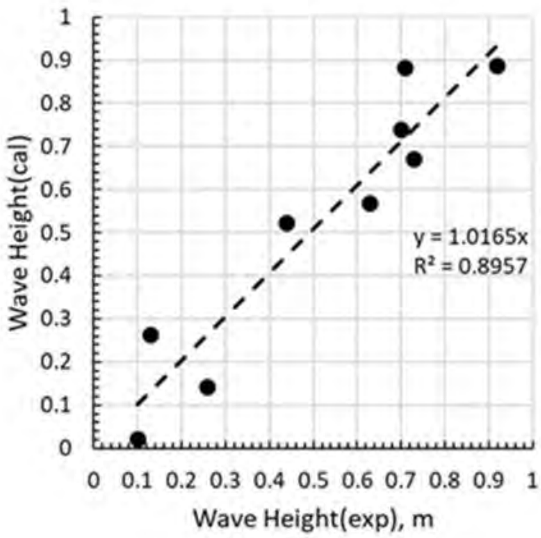


Figure 7-88 Correlation of experimental wave heights and calculated ones, second groin + submerged breakwater 20 m

【Reproducibility of nearshore currents】

Figure 7-89 shows the result of calculation on nearshore currents, and locations of current meters. Figure 7-90 shows the comparison of nearshore currents measured in the experiment and estimated by the calculation. Figure 7-91 shows correlation of these two kinds of nearshore currents. Referring to these figures, it is confirmed that experimental results are almost accurately reproduced by the calculation.

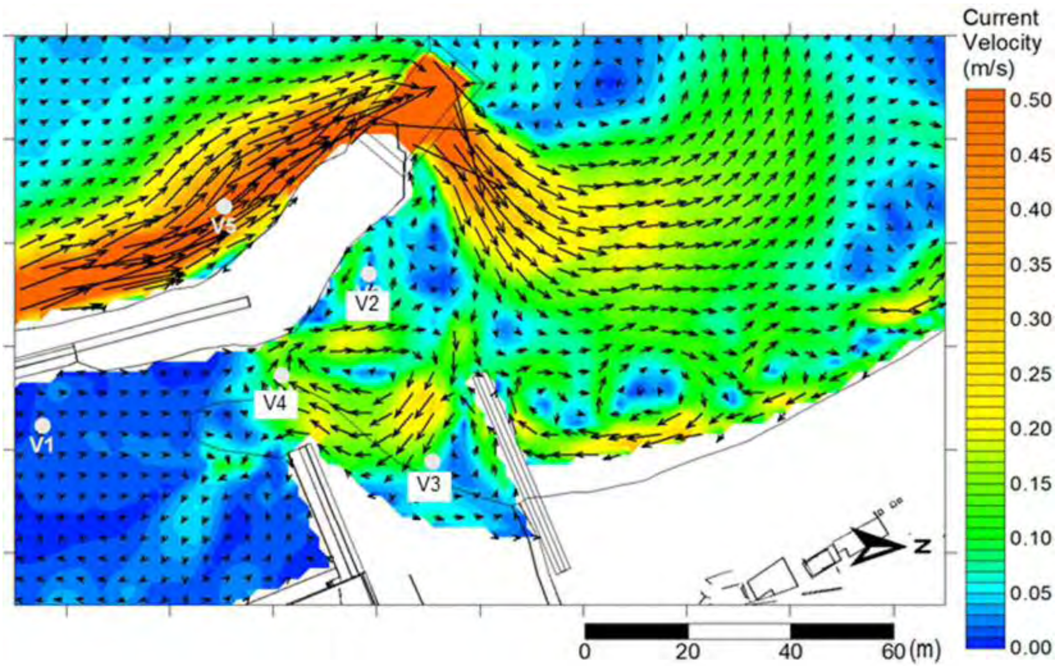


Figure 7-89 Result of calculation on nearshore currents, and locations of current meters, second groin + submerged breakwater 20m

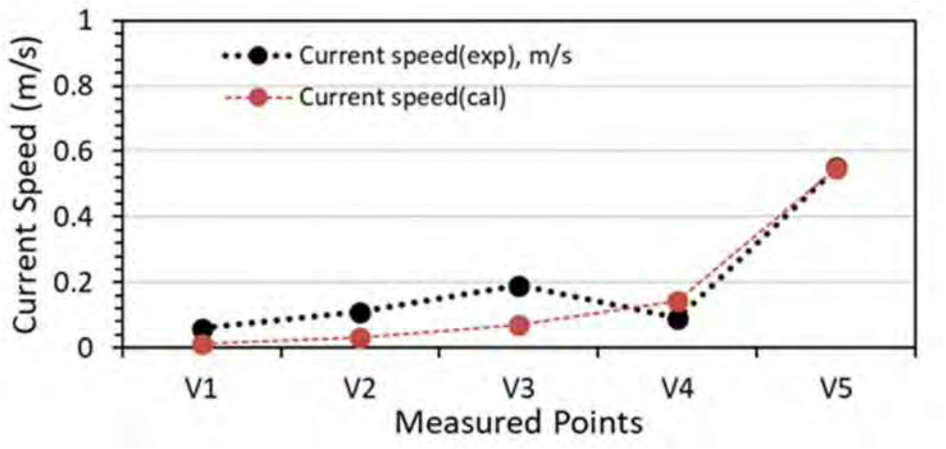


Figure 7-90 Comparison of experimental results and calculated ones of nearshore currents, second groin + submerged breakwater 20 m

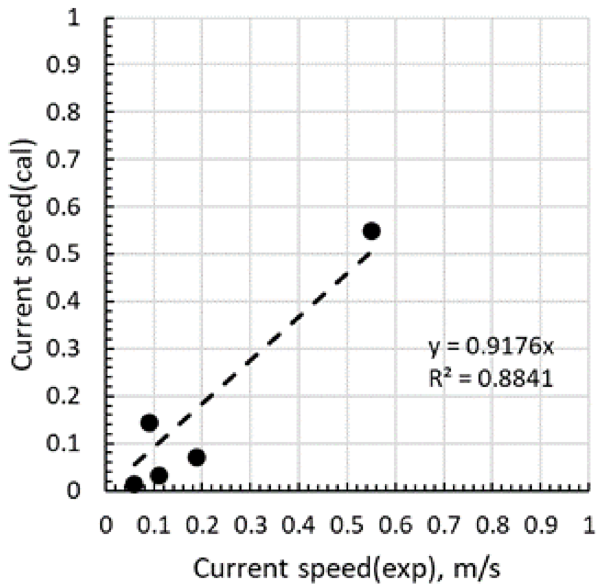
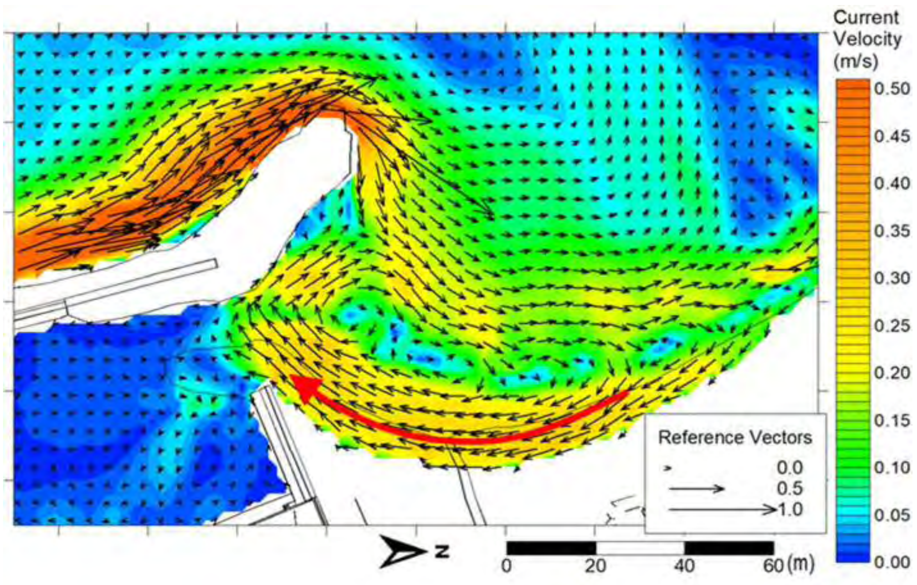


Figure 7-91 Correlation of experimental results and calculated ones of nearshore currents, second groin + submerged breakwater 20 m

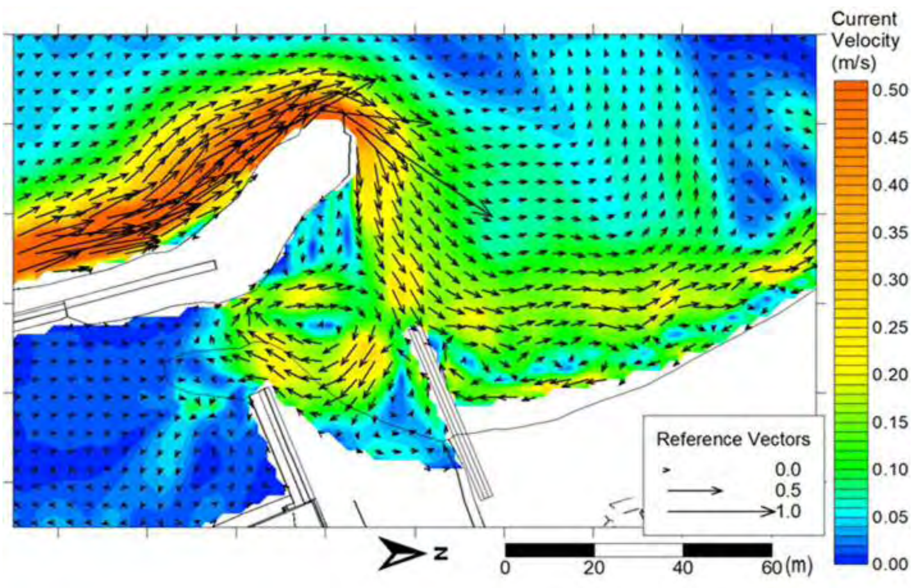
7.3.2 Confirmation of effect of countermeasure by simulation

(1) Effect of second sand groin

Figure 7-92 shows comparison of nearshore currents with or without the second groin. Without the second groin (a), a big circulating currents in clockwise direction is generated and sediment transport occurs from the north beach toward the port mouth. On the contrary, with the second groin (b), southward currents of the big circulation in clockwise direction is blocked and effect of controlling the sediment transport toward the port mouth is confirmed.



(a) Present condition, without second groin



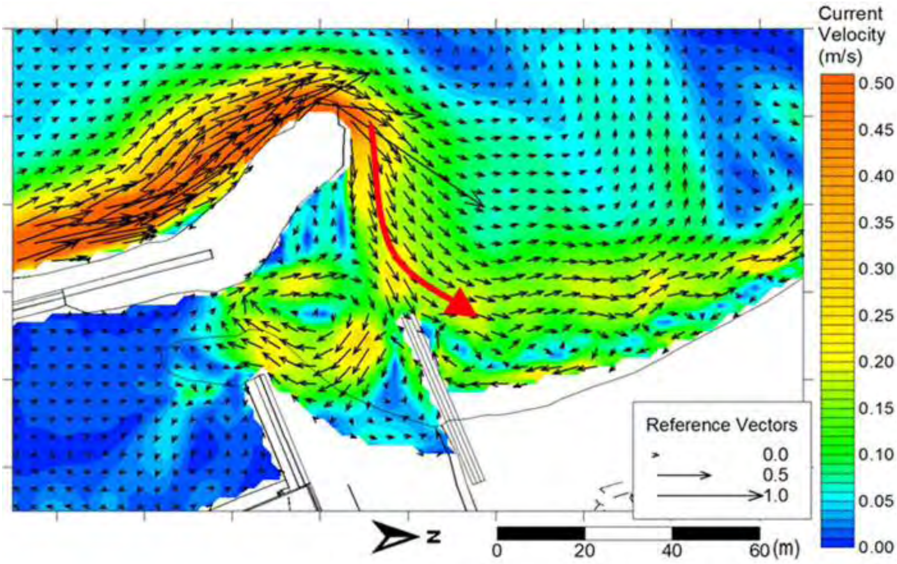
(b) After installation of second groin

Figure 7-92 Difference of nearshore currents between with and without second groin

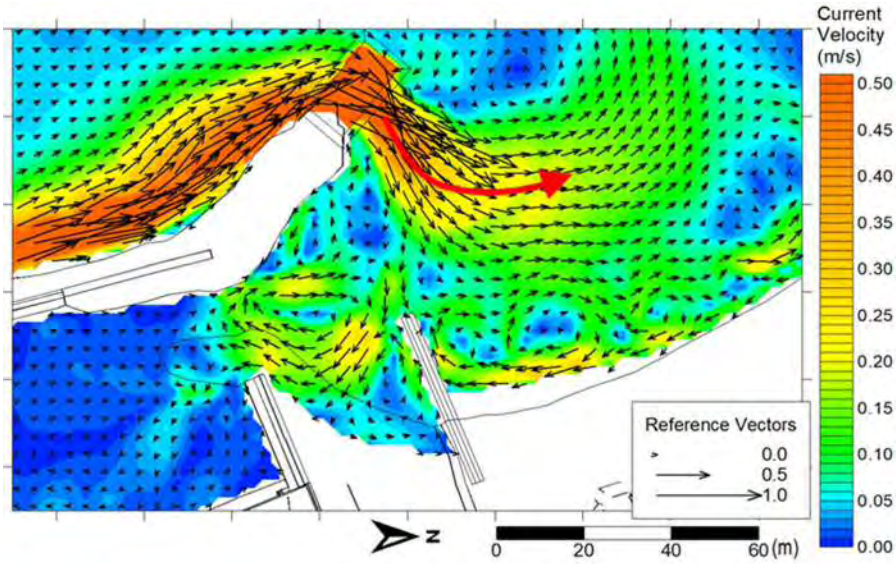
(2) Effect of submerged breakwater

Effect brought by submerged breakwater to be constructed at the tip of additional breakwater can be confirmed in Figure 7-93.

Without the submerged breakwater (a), currents passing nearby the tip of additional breakwater go toward the second groin. In the other hand, with the submerged breakwater (b), effect of promoting sediment transport to the north beach is expected because northeastward strong currents, which decrease the possibility of sediment inflow to inside the port, is generated above the submerged breakwater.



(a) without submerged breakwater



(b) with submerged breakwater of 20 m

Figure 7-93 Difference of nearshore currents between with and without submerged breakwater

(3) Influence of installation direction of submerged breakwater

Figure 7-94 shows nearshore currents, where the direction of 20m submerged breakwater is rotated at 30 degree in counterclockwise direction (hydraulic model experiment in this case is not executed). In comparison with the nearshore currents in Figure 7-93 (b), current velocity and current direction above and behind the submerged breakwater differ.

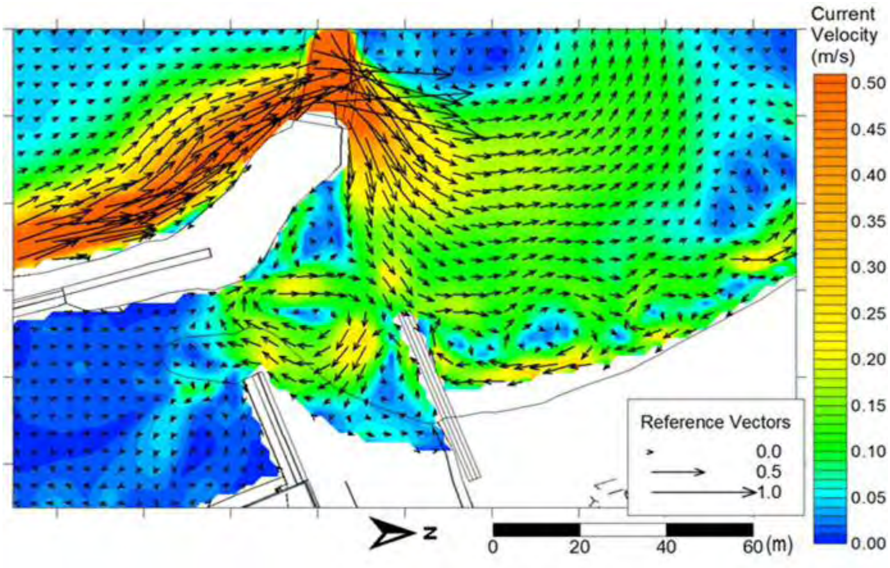


Figure 7-94 Nearshore currents, where the direction of 20 m submerged breakwater is rotated at 30 degrees in counterclockwise direction

Figure 7-95 and Figure 7-96 are made to compare nearshore current vectors in Figure 7-93 (b) and Figure 7-94. Both current velocity vectors are superimposed in Figure 7-95, and Figure 7-96 indicates the differences of vectors. According to these figures, differences of current velocity vectors are clearly found above and behind the submerged breakwater. In case that the submerged breakwater is rotated at 30 degrees in counterclockwise direction, it seems that current velocity from the base of submerged breakwater to inside of the port becomes stronger and promoting effect of sediment transport to north beach becomes weaker.

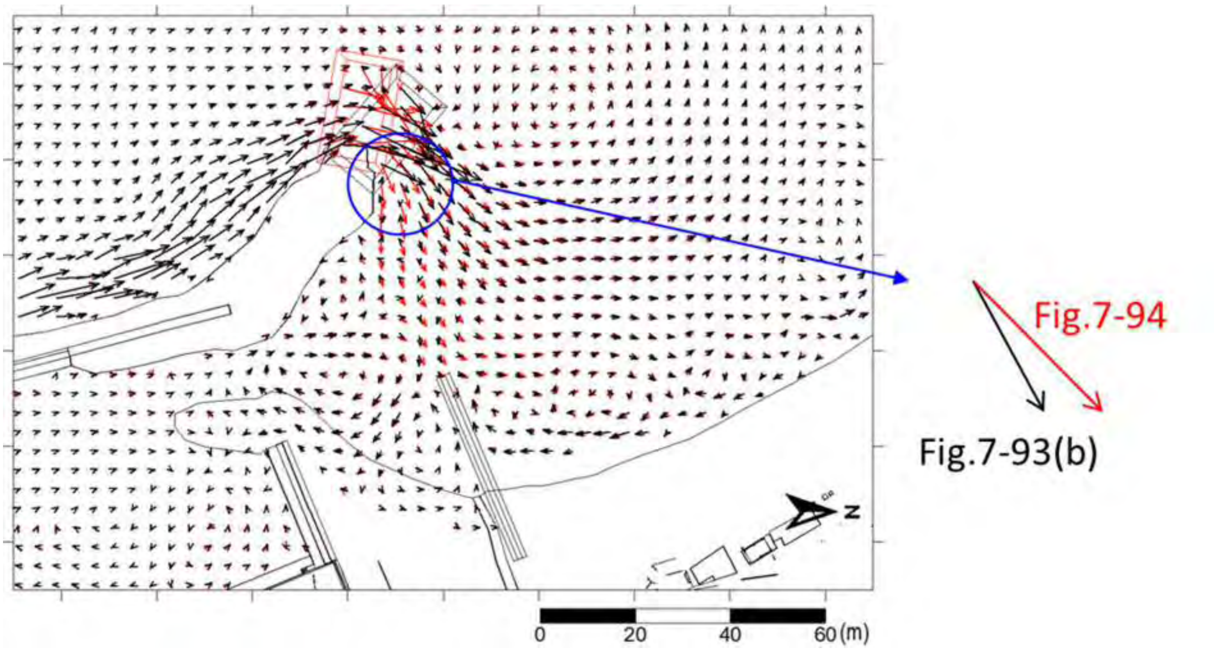


Figure 7-95 Superimposed current velocity vectors by difference of installation direction of submerged breakwater

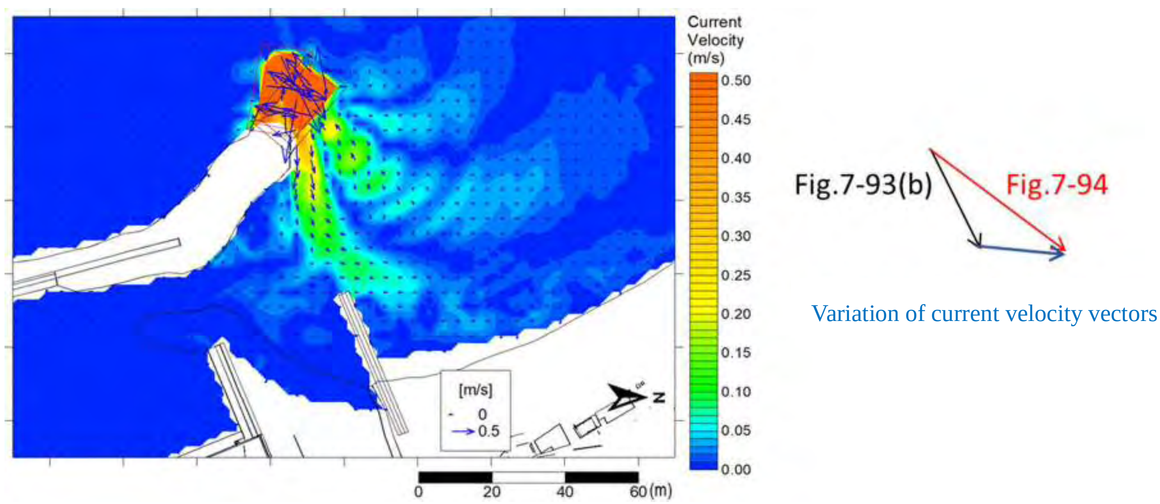


Figure 7-96 Difference of current velocity vectors by difference of installation direction of submerged breakwater

7.4 Function and effect of countermeasure

【Second sand groin】

The second groin has a function of blocking the sediment transport of route 1, refer to Figure 7-97. Route 1 is longshore sand transport from the north beach, right side in the figure, to the area sheltered by the additional breakwater. The existing groin at the port entrance does not have enough length, so sediment is transported beyond the groin and causes the deposition. The port entrance is narrowed if the existing groin is extended, so the sediment transport of route 1 is blocked by constructing second groin on the north side. In order to confirm the sheltering function and effect of second groin, the calculation of shoreline change and the fixed bed model experiment using tracers have been conducted.

After construction of second groin, the shoreline configuration formulated on the north beach is in equilibrium and stable, and the southward sediment transport, going toward the port, does not occur.

【Submerged breakwater】

The submerged breakwater has a function of changing the direction of sand transport of route 2, referring to Figure 7-97. The sand transported through route 2 is a part of the northward longshore sand drift along the breakwater, which wraps around the tip of additional breakwater and goes toward inside of the port. Since it is impossible to block the northward sand drift, changing the route toward the port is needed so that the sand is transported toward the north beach. By conducting numerical simulation on wave deformation and nearshore currents, and fixed bed model experiment using tracers, it is confirmed that submerged breakwater has such functions.

Function of submerged breakwater is effectively performed in combination with several hydraulic characteristics as follows:

* Weak sheltering effect from waves,
* Prevention of sand wraparound,
* Scouring in the area behind submerged breakwater,
* Rapid current toward land generated on the submerged breakwater.

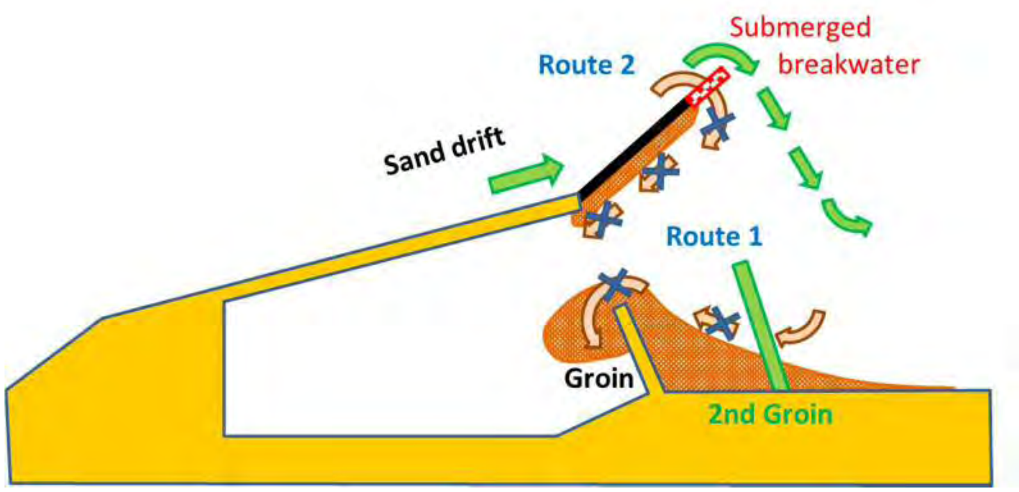


Figure 7-97 Explanatory diagram for function and effect of countermeasures

Figure 7-98 shows the detailed construction locations of the second groin and the submerged breakwater.

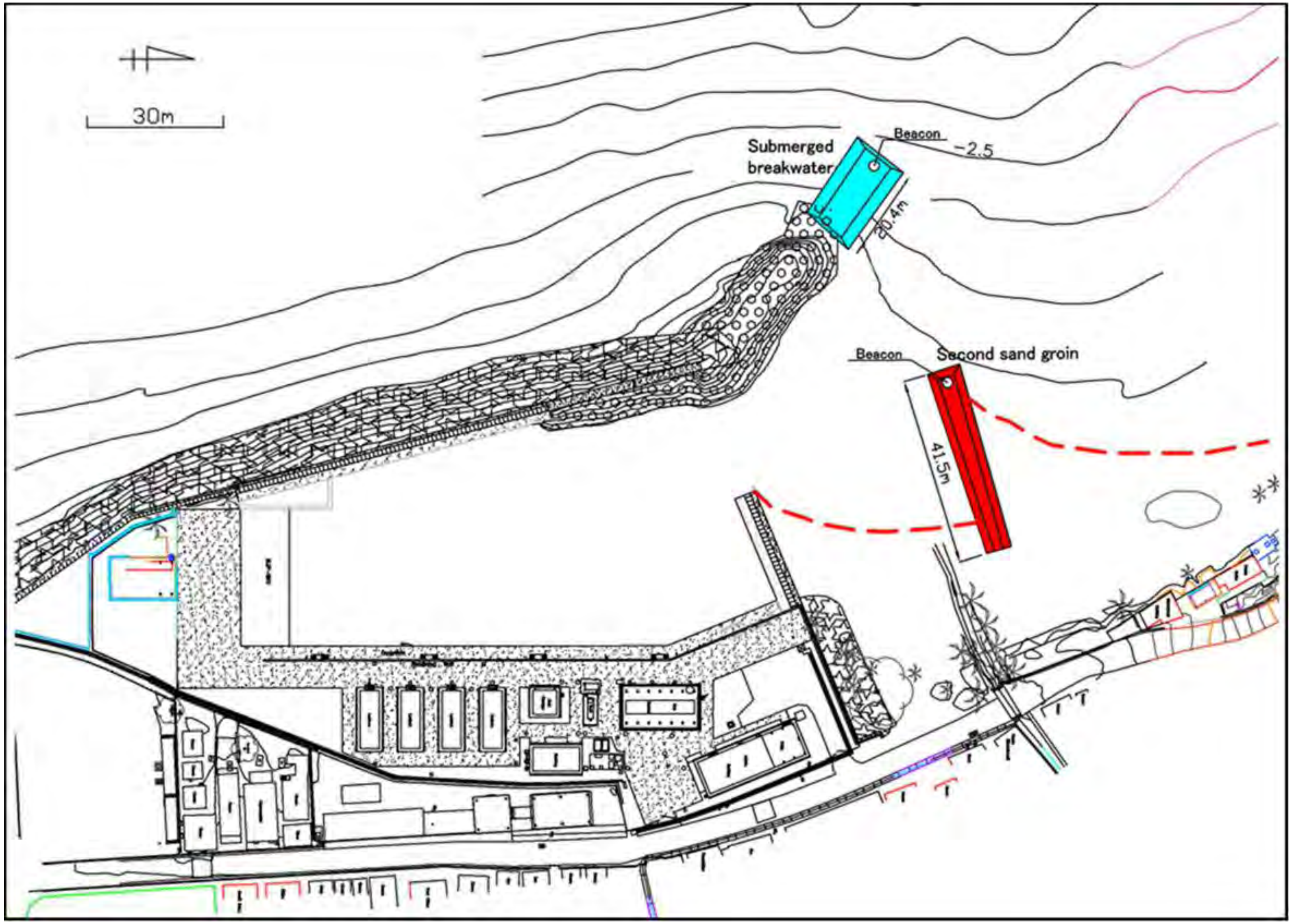


Figure 7-98 Layout of countermeasures, second groin and submerged breakwater

7.5 Project cost estimation by countermeasure

Two countermeasures below are considered, and these countermeasures are compared in terms of the project cost and maintenance cost for 30 years. In cost estimation, the maintenance cost is borne by the recipient country.

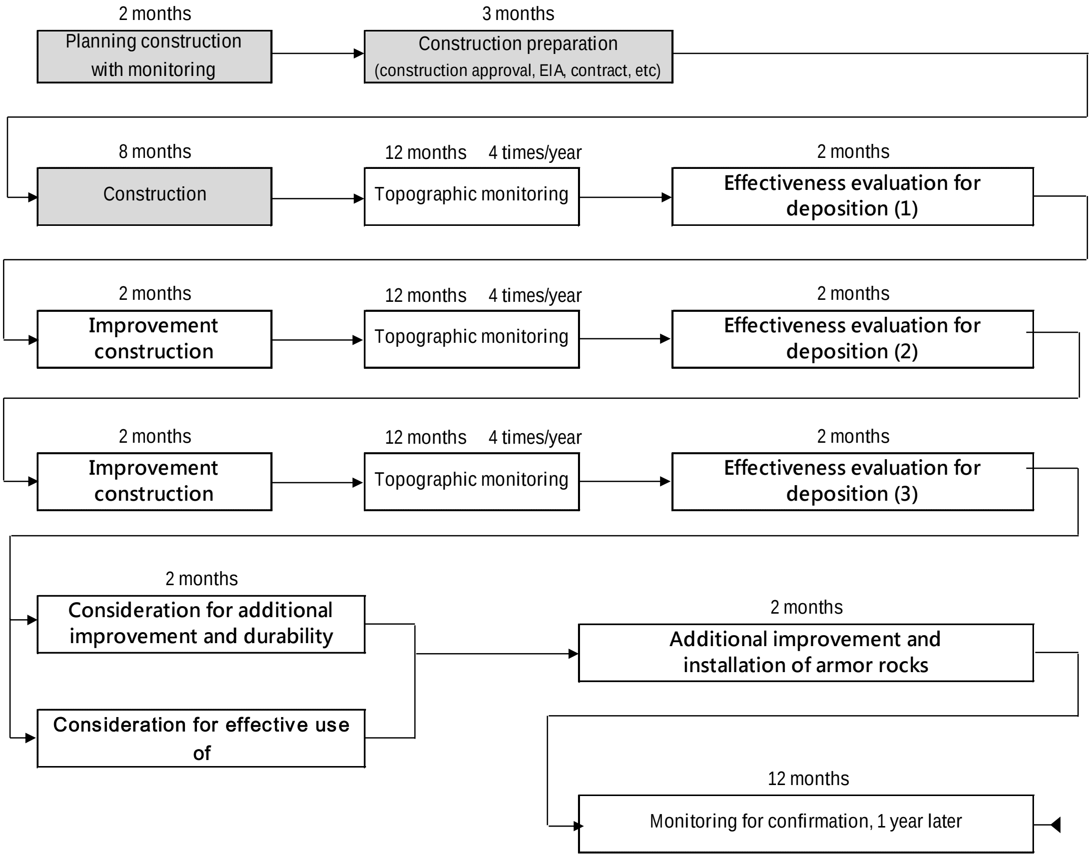
Table 7-7 is the comparison table of project cost for each countermeasure. Both life cycle costs for 30 years are nearly equivalent. However, for the recipient country, countermeasure-1 has an advantage as for the future maintenance cost.

(1) Countermeasure-1: Prevention measure for deposition in the port by facility construction (construction with monitoring)

Countermeasure plan proposed in this study is to construct the second sand groin and submerged breakwater. By the second sand groin, sand coming from Route 1 is blocked, and submerged breakwater is planned to prevent the deposition around port entrance by inducing sand to north beach indicated as Route 2.

The project cost is estimated based on the following conditions: the construction works are to be carried out only by local construction company under the supervision by Japanese consultant, and the construction works to be proceeded step by step with monitoring and intermediate evaluation and analysis. The maintenance cost after completion is assumed to be 1/10 of the one estimated in countermeasure-2 (zero option).

Conceptual diagram of the construction is shown in Figure 7-99 below.



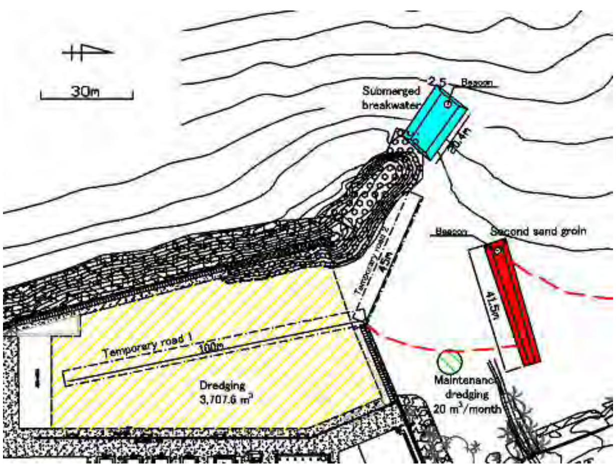
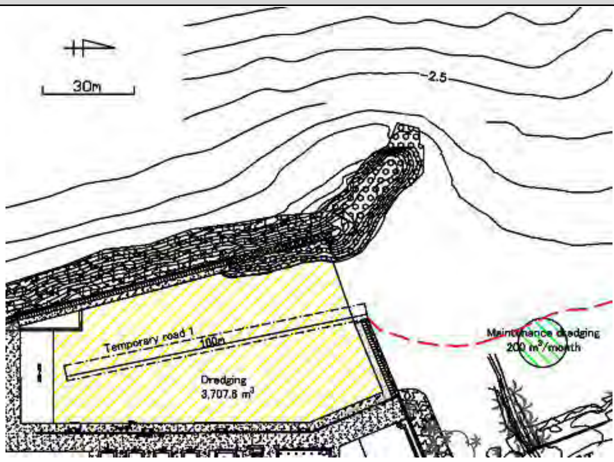
Note: The EIA usually takes 6 months, therefore the application should be started prior to the time of monitoring planning.

Figure 7-99 Conceptual diagram of the construction

(2) Countermeasure-2: Zero option

This countermeasure assumes that maintenance dredging is to be continued for 30 years to secure necessary water depth in the port and port entrance without constructing any countermeasure facilities for deposition in the port.

Table 7-7 Comparison table of project cost by countermeasure

<table>
<tr><th colspan="2">Countermeasure-1: Prevention of deposition in the port by facility construction (construction with monitoring)</th><th>Items</th><th>Approximate project cost (million yen)</th></tr>
<tr><td rowspan="3">Borne by Japan</td><td rowspan="5">
</td><td>① Construction cost:
－Construction with monitoring
Dredging in the port, construction of second groin and submerged breakwater
－Improvement construction
－Finishing construction after monitoring</td><td>305.0</td></tr>
<tr><td>② Design and supervision cost:
－Detailed Design
－Construction supervision
Experimental construction and improvement construction
－Monitoring and analysis (2 times)
－Inspections (completion, defect)</td><td>266.8</td></tr>
<tr><td>Total amount borne by Japan</td><td>571.8</td></tr>
<tr><td rowspan="2">Borne by recipient country</td><td>－Maintenance cost (30 years)</td><td>43.9</td></tr>
<tr><td>Total amount borne by recipient country</td><td>43.9</td></tr>
<tr><th colspan="2">Countermeasure-2: Zero option</th><th>Items</th><th>Approximate project cost (million yen)</th></tr>
<tr><td rowspan="2">Borne by Japan</td><td rowspan="4">
</td><td></td><td></td></tr>
<tr><td>Total amount borne by Japan</td><td>0</td></tr>
<tr><td rowspan="2">Borne by recipient country</td><td>－Dredging in the port
－Maintenance cost (30 years)</td><td>517.8</td></tr>
<tr><td>Total amount borne by recipient country</td><td>517.8</td></tr>
</table>

From the cost estimates above, following analysis is obtained.

① Comparison between countermeasure-1 and countermeasure-2

When the whole project costs (cost borne by Japan and borne by recipient country) including life cycle cost for 30 years are compared, the cost for countermeasure-1 is approximately 100 million yen more expensive than countermeasure-2.

② Comparison of maintenance cost

Based on the results of numerical simulation and hydraulic model experiment, maintenance cost for 30 years in case of countermeasure-1 is assumed to be 1/10 compared to the maintenance cost for countermeasure-2 that requires 200m^3/month dredging for maintaining shoreline. In case of countermeasure-1, present dredging frequency (once in a month) is expected to be fewer down to once in a year.

7.6 Order of construction

For the construction of countermeasure-1, hopefully second sand groin is constructed prior to dredging works. For dredging works and construction of submerged breakwater, construction machine and equipment which are possible to be procured by a local contractor are backhoe, crawler cranes and dump trucks, therefore on-land construction with making temporary road is the basic idea of construction.

During construction period, the port entrance is closed. Thus, temporary facilities such as jetties are hopefully installed on the north beach to mitigate the impacts on existing fishing boats.

【Order of Construction】(Refer to Figure 7-100)

① Second groin

② Dredging works

③ Submerged breakwater

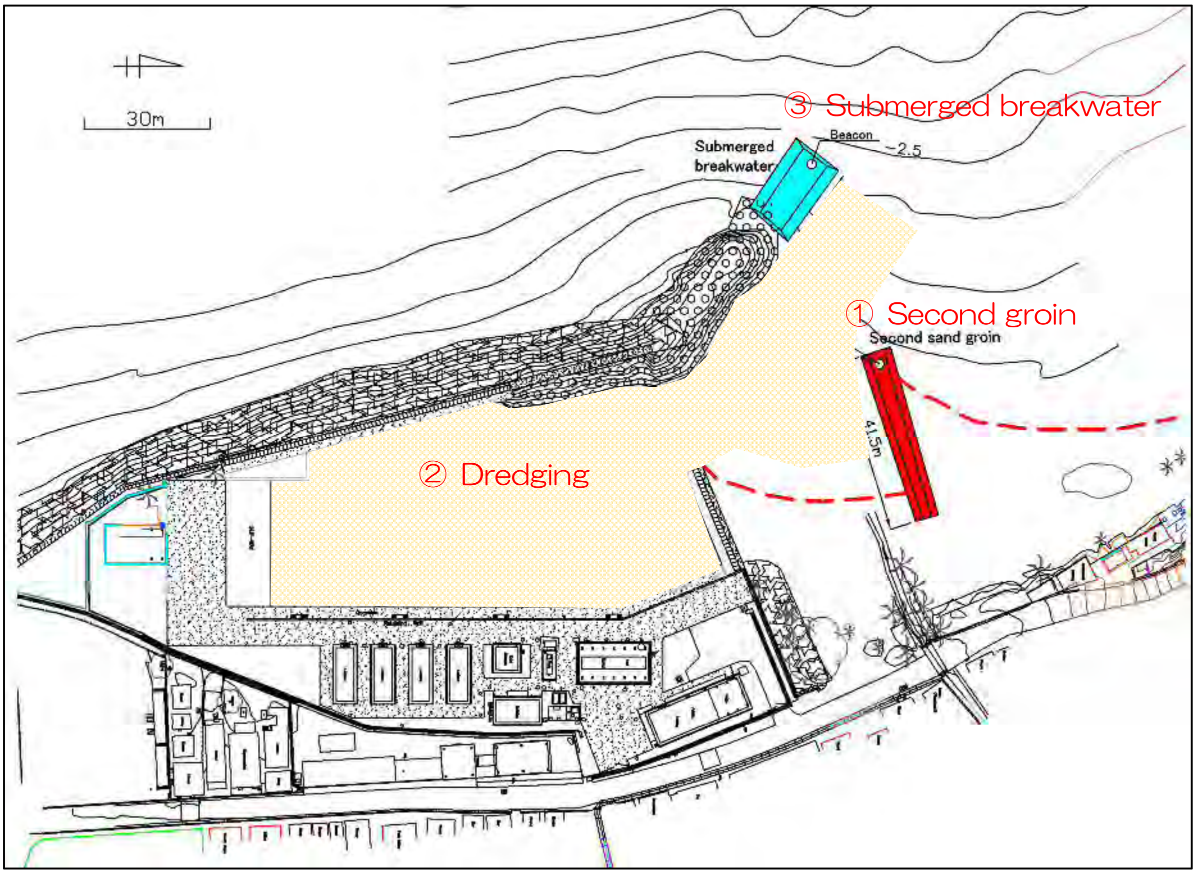


Figure 7-100 Order of construction for countermeasure-1

Appendix

【Appendix】

Appendix - 1 List of Survey Team

(1) First Phase

Survey team members are as follows.

Name	Assignment	Sector
Kazuya SUZUKI	Leader	Deputy Director Rural Development Department JICA
Makoto IKEDA	Planning Coordinator	Rural Development Department JICA
Kazumasa KATO	Chief Consultant/ Fishing Port Planning	ECOH CORPORATION
Hitoshi TAKEMOTO	Facility Planning (1)/ Natural Condition Survey (1)/ Environmental Consideration	ECOH CORPORATION
Takahiro YAMADA	Facility Planning (2)/ Protection Measure against Sand Drifting	ECOH CORPORATION
Shuji SAKAI	Maintenance Dredging/ Cost Estimation	ECOH CORPORATION
Takumu SUZUKI	Natural Condition Survey (2)	ECOH CORPORATION

(2) Second Phase

Survey team members are as follows.

Name	Assignment	Sector
Kazuya SUZUKI	Leader	Deputy Director Rural Development Department JICA
Hisakatsu OKUDA	Planning Coordinator	Rural Development Department JICA
Kazumasa KATO	Chief Consultant/ Fishing Port Planning	ECOH CORPORATION
Nobuyuki ONO	Numerical Simulation In Second Phase	ECOH CORPORATION
Iwao HASEGAWA	Hydraulic Model Test	ECOH CORPORATION
Kenji KUROKI	Coordinator/Cost Estimate	ECOH CORPORATION
Kazuma OHASHI	Coordinator (Contact)	ECOH CORPORATION

Appendix - 2 Survey Schedule

(1) First Site Survey (Nov. 7, 2017 to Dec. 20, 2017)

Table-2.1 Schedule of first site survey (first phase)

Date in St.Lucia	Date in Japan	Day of the week	Duration		JICA schedule	Field study team member: Dr. Kazumasa KATO (Team Leader/Fishing Port Planning)	Mr. Hitoshi TAKEMOTO (Facility Planning(1)/Natural Conditon Survey(1)/environmentalal Consideration)	Mr. Takahiro YAMADA (Facility Planning(2)/Protection measure against Sand Drifting)	Mr. Shuji SAKAI (Maintenance Dredging/Cost Estimation)	Mr. Takumu SUZUKI (Natural Condition Survey(2))
Nov. 7	Nov. 7	Tue.	1			Tokyo⇒Atlanta (DL 296, Dep.17:30⇒Arr.15:59) Stay at Atlanta				Tokyo⇒Atlanta (DL 296, Dep.17:30⇒Arr.15:59) Stay at Atlanta
Nov. 8	Nov. 8	Wed.	2			Atlanta⇒St.Lucia (DL339, Dep.9:50⇒Arr.15:22)				Atlanta⇒St.Lucia (DL339, Dep.9:50⇒Arr.15:22)
Nov. 9	Nov. 9	Thu.	3			Courtesy visit to St. Lucia JICA office at 9:30				Courtesy visit to St. Lucia JICA office at 9:30
Nov. 10	Nov. 10	Fri.	4			Project site survey at 9:00				Project site survey at 9:00
Nov. 11	Nov. 11	Sat.	5			Project site survey				Project site survey
Nov. 12	Nov. 12	Sun.	6		Mr. Kazuya SUZUKI Mr. Makoto IKEDA	Meeting in the team, Preparation of report				Meeting in the team, Preparation of report
Nov. 13	Nov. 13	Mon	7		Arrive at St. Lucia	Explanation of IC/R at MOAF&C St. Lucia?	Explanation of IC/R at MOAF&C St. Lucia?	Natural condition survey		Natural Condition Survey
Nov. 14	Nov. 14	Tue	8		Courtesy visit to MOAF&C at 10:00 and Minutes of discussion	Attending to minutes of discussion	Attending to minutes of discussion	Support for installation of hydrographic condition measuring device		Support for installation of hydrographic condition measuring device
Nov. 15	Nov. 15	Wed	9		Minutes of discussion	Attending to minutes of discussion	Attending to minutes of discussion	Sediment survey		Natural condition survey
Nov. 16	Nov. 16	Thu	10		Signing minutes / St. Lucia ⇒ POS Stay at POS	Signing minutes / St. Lucia⇒POS (BA2159 Dep.15:55⇒	Signing minutes / St. Lucia⇒POS (BA2159 Dep.15:55⇒	Sediment survey		Natural condition survey
Nov. 17	Nov. 17	Fri	11		Explanation at Japanese Embassy / POS⇒Japan	Explanation at Japanese Embassy / POS⇒St. Lucia (BA2158 Dep.18:45⇒	Explanation at Japanese Embassy / POS⇒St. Lucia (BA2158 Dep.18:45⇒	Natural condition survey		Natural condition survey
Nov. 18	Nov. 18	Sat	12			Field survey	Field survey	Field survey		Field survey
Nov. 19	Nov. 19	Sun	13			Meeting in the team, Preparation of report				Meeting in the team, Preparation of report
Nov. 20	Nov. 20	Mon	14			Field survey	Field survey	Field survey		Field survey
Nov. 21	Nov. 21	Tue	15			Weekly meeting with MOAF&C St. Lucia	Weekly meeting with MOAF&C St. Lucia	Natural condition survey		Natural condition survey
Nov. 22	Nov. 22	Wed	16			Field survey	Survey for operation and maintenance of the Choiseul fishing port	Field survey		Field survey
Nov. 23	Nov. 23	Thu	17			Field survey	Survey for port and fishery facilities in St. Lucia	Field survey		Field survey
Nov. 24	Nov. 24	Fri	18			Natural condition survey	Survey for port and fishery facilities in St. Lucia	Natural condition survey		Natural condition survey
Nov. 25	Nov. 25	Sat	19			Field survey	Field survey	Natural condition survey		Field survey
Nov. 26	Nov. 26	Sun	20	1		Meeting in the team, Preparation of report			Tokyo⇒Atlanta (DL 296, Dep.17:30⇒ Arr.15:59) Stay at Atlanta	Meeting in the team, Preparation of report
Nov. 27	Nov. 27	Mon	21	2		Collecting information of natural condition	Survey for port and fishery facilities in St. Lucia	Natural condition survey	Atlanta⇒St. Lucia (DL339, Dep.9:50 ⇒Arr.15:22)	Natural condition survey
Nov. 28	Nov. 28	Tue	22	3		Weekly meeting with MOAF&C St. Lucia	Weekly meeting with MOAF&C St. Lucia	Natural condition survey	Weekly meeting with MOAF&C St. Lucia	Natural condition survey
Nov. 29	Nov. 29	Wed	23	4	Mr. Ichiro MIMURA	Collecting information of natural condition	environmental survey	Natural condition survey	Hearing to Choiseul fishing port related person	Natural condition survey

Table-2.2 Schedule of first site survey (first phase)

Nov. 30	Nov. 30	Thu	24	5	Arrive at St. Lucia	Meeting in the team	Collecting information of natural condition	Meeting in the team	environmental survey	Meeting in the team	Natural condition survey	Meeting in the team	Collecting dredging record at MOAF&C	Meeting in the team	Natural condition survey	Meeting in the team
Dec. 1	Dec. 1	Fri	25	6	Participation to another mission	Field survey	Natural condition survey	Field survey	Natural condition survey	Field survey	Natural condition survey		Survey for general contractor in St. Lucia		Natural condition survey	
Dec. 2	Dec. 2	Sat	26	7			Field survey		Field survey		Natural condition survey		Survey for quarry in St. Lucia		Field survey	
Dec. 3	Dec. 3	Sun	27	8			Meeting in the team, Preparation of report									
Dec. 4	Dec. 4	Mon	28	9			Making a draft report before returning to Japan		Making a draft report before returning to Japan		Natural condition survey		Survey for procurement in St. Lucia		Natural condition survey	
Dec. 5	Dec. 5	Tue	29	10			Courtesy visit to MOAF&C St. Lucia and JICA office before returning to Japan						Meeting at JICA office with MOAF&C St. Lucia		Courtesy visit to MOAF&C St. Lucia and JICA office before returning to Japan	
Dec. 6	Dec. 6	Wed	30	11			St. Lucia ⇒ Atlanta(DL349, Dep.16:15⇒Arr.20:18), Stay at Atlanta						Support to natural condition survey		St. Lucia ⇒Atlanta (DL349, Dep.16:15⇒Arr.20:18), Stay at Atlanta	
Dec. 7	Dec. 7	Thu	31	12			Atlanta⇒Tokyo (DL295, Dep.11:18⇒Arr.15:45)						Weekly meeting with MOAF&C St. Lucia		Atlanta⇒Tokyo (DL295, Dep.11:18 ⇒Arr.15:45)	
Dec. 8	Dec. 8	Fri	32	13									Survey for construction information			
Dec. 9	Dec. 9	Sat		14									Survey for procurement information			
Dec. 10	Dec. 10	Sun		15									Making report			
Dec. 11	Dec. 11	Mon		16									Support to natural condition survey			
Dec. 12	Dec. 12	Tue		17									Support to natural condition survey			
Dec. 13	Dec. 13	Wed		18									Weekly meeting with MOAF&C St. Lucia			
Dec. 14	Dec. 14	Thu		19									Support to natural condition survey			
Dec. 15	Dec. 15	Fri		20									Courtesy visit to MOAF&C St. Lucia and JICA office before returning to Japan			
Dec. 16	Dec. 16	Sat		21									Support to remove the equipment			
Dec. 17	Dec. 17	Sun		22									Support to remove the equipment			
Dec. 18	Dec. 18	Mon		23									St. Lucia ⇒Atlanta (DL349, Dep.16:15⇒Arr.20:18), Stay at Atlanta			
Dec. 19	Dec. 19	Tue		24									Atlanta⇒Tokyo (DL295, Dep.11:18 ⇒Arr.15:45)			
Dec. 20	Dec. 20	Wed		25												
Dec. 21	Dec. 21	Thu														
Dec. 22	Dec. 22	Fri														
Dec. 23	Dec. 23	Sat														
Dec. 24	Dec. 24	Sun														
Dec. 25	Dec. 25	Mon														
Dec. 26	Dec. 26	Tue														
Dec. 27	Dec. 27	Wed														

(2) Second site survey (July 31, 2018 to Sep. 15, 2018)

Table – 2.3 Schedule of second site survey (first phase)

Duration		Date		Second site works team member			
				Dr. Kazumasa KATO	Mr. Takumu SUZUKI	Mr. Shuji SAKAI	Mr. Takahiro YAMADA
				Team Leader/Fishing Port Planning	Natural Condition Survey (2)	Maintenance Dredging/ Cost Estimation	Facility Planning (2)/ Protection measure against Sand Drifting
1		Jul. 31	Tue	Tokyo(DL 296, Dep. 16:30) ⇒Atlanta(Arr. 16:11)			
2		Aug. 1	Wed	Atlanta(DL339, Dep. 9:50)⇒St.Lucia (Arr. 14:30)			
3		Aug. 2	Thu	Courtesy visit to MOAF&C and JICA			
4		Aug. 3	Fri	Field survey			
5		Aug. 4	Sat	Field survey & data collection	Natural condition survey		
6		Aug. 5	Sun	Prepare the document for explanation to MOAF&C			
7		Aug. 6	Mon	Field survey	Installation of hydrograhic condition measuring device		
8		Aug. 7	Tue	Explanation for results of First field survey at MOAF&C			
9		Aug. 8	Wed	Field survey & data collection	Natural condition survey		
10		Aug. 9	Thu	Field survey & data collection	Natural condition survey		
11		Aug. 10	Fri	Field survey & data collection	Natural condition survey		
12		Aug. 11	Sat	Field survey & data collection	Natural condition survey		
13		Aug. 12	Sun	Arrangement and organize the data			
14		Aug. 13	Mon	Field survey	Checking the equipment		
15		Aug. 14	Tue	Field survey & data collection	Natural condition survey		
16		Aug. 15	Wed	Field survey & data collection	Natural condition survey		
17		Aug. 16	Thu	Field survey & data collection	Natural condition survey		
18		Aug. 17	Fri	Field survey & data collection	Natural condition survey		
19		Aug. 18	Sat	Field survey & data collection	Natural condition survey		
20		Aug. 19	Sun	Arrangement and organize the data			
21	1	Aug. 20	Mon	Field survey	Checking the equipment	Tokyo(DL 296, Dep. 16:30)⇒Atlanta(Arr. 16:11)	
22	2	Aug. 21	Tue	Field survey & data collection	Natural condition survey	Atlanta (DL339, Dep. 9:50)⇒St.Lucia(Arr. 14:30)	
23	3	Aug. 22	Wed	Meeting in the team and field survey			
24	4	Aug. 23	Thu	Preparing the interim report		Survey for maintenance dredging	Survey for sand drifting
25	5	Aug. 24	Fri	Explanation of the interim report at MOAF&C and JICA			
26	6	Aug. 25	Sat	Field survey		Survey for maintenance dredging	Survey for sand drifting
27	7	Aug. 26	Sun	Arrangement and organize the data			
28	8	Aug. 27	Mon	St. Lucia(DL349, Dep.15:29) ⇒ Atlanta (Arr. 20:14)		Survey for maintenance dredging	Checking the equipment
29	9	Aug. 28	Tue	Atlanta(DL295, Dep.11:49) ⇒		Survey for maintenance dredging	Survey for sand drifting
30	10	Aug. 29	Wed	⇒Tokyo (Arr. 14:35)		Survey for maintenance dredging	Survey for sand drifting
	11	Aug. 30	Thu			Survey for maintenance dredging	Survey for sand drifting
	12	Aug. 31	Fri			Survey for maintenance dredging	Survey for sand drifting
	13	Sep. 1	Sat			Survey for maintenance dredging	Survey for sand drifting
	14	Sep. 2	Sun			Arrangement and organize the data	
	15	Sep. 3	Mon			Survey for maintenance dredging	Checking the equipment
	16	Sep. 4	Tue			Survey for cost estimation	Survey for facility planning
	17	Sep. 5	Wed			Survey for cost estimation	Survey for facility planning
	18	Sep. 6	Thu			Survey for cost estimation	Survey for facility planning
	19	Sep. 7	Fri			Survey for cost estimation	Survey for facility planning
	20	Sep. 8	Sat			Survey for cost estimation	Survey for facility planning
	21	Sep. 9	Sun			Arrangement and organize the data	
	22	Sep. 10	Mon			Survey for cost estimation	Removal of the equipment
	23	Sep. 11	Tue			Survey for cost estimation	Survey for facility planning
	24	Sep. 12	Wed			Meeting at MOAF&C and JICA	
	25	Sep. 13	Thu			St. Lucia(DL349, Dep.15:30) ⇒Atlanta(Arr.20:13)	
	26	Sep. 14	Fri			Atlanta(DL295, Dep.11:20)⇒	
	27	Sep. 15	Sat			⇒Tokyo (Arr.14:35)	

(3) Third site survey (Jan. 25, 2020 to Feb. 3, 2020)

Table – 2.4 Schedule of third site survey (second phase)

<table>
<tr><th rowspan="3">period</th><th rowspan="3">Day</th><th rowspan="3">Day of the week</th><th colspan="5">Survey Team</th></tr>
<tr><th>Kazuya SUZUKI</th><th>Hisakatsu OKUDA</th><th>Kazumasa KATO</th><th>Kenji KUROKI</th><th>Kazuma OHASHI</th></tr>
<tr><th>Leader</th><th>Planning Coordinator</th><th>Chief Consultant</th><th>Coordinator/Cost Estimate</th><th>Coordinator (contact)</th></tr>
<tr><td>1</td><td>1/25</td><td>Sat</td><td colspan="2">Tokyo - London</td><td colspan="3">Tokyo - Toronto</td></tr>
<tr><td>2</td><td>1/26</td><td>Sun</td><td colspan="2">London - Saint Lucia</td><td colspan="3">Toronto - Saint Lucia</td></tr>
<tr><td>3</td><td>1/27</td><td>Mon</td><td colspan="5">Meeting at JICA office / Meeting with Department of Fisheries</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">1/28</td><td rowspan="2">Tue</td><td colspan="5">Minutes meeting / Site visit / Explanation to Choiseul fishing port users</td></tr>
<tr><td>Saint Lucia - London</td><td colspan="4"></td></tr>
<tr><td>5</td><td>1/29</td><td>Wed</td><td>London - Tokyo</td><td>Preparation for signing</td><td colspan="3">Construction environment survey</td></tr>
<tr><td rowspan="2">6</td><td rowspan="2">1/30</td><td rowspan="2">Thu</td><td rowspan="2"></td><td colspan="4">Sigining ceremony</td></tr>
<tr><td colspan="2">Saint Lucia - Torinidad & Tobago (POS)</td><td colspan="2"></td></tr>
<tr><td rowspan="2">7</td><td rowspan="2">1/31</td><td rowspan="2">Fri</td><td rowspan="2"></td><td colspan="2">Explanation to Ambassader</td><td colspan="2" rowspan="2">Construction environment survey</td></tr>
<tr><td>POS - London</td><td>POS - Saint Lucia</td></tr>
<tr><td rowspan="2">8</td><td rowspan="2">2/1</td><td rowspan="2">Sat</td><td rowspan="2"></td><td rowspan="2">London -</td><td colspan="3">Site visit to Choiseul fishing port</td></tr>
<tr><td colspan="3">Saint Lucia - Toronto</td></tr>
<tr><td>9</td><td>2/2</td><td>Sun</td><td></td><td>- Tokyo</td><td colspan="3">Toronto -</td></tr>
<tr><td>10</td><td>2/3</td><td>Mon</td><td></td><td></td><td colspan="3">- Tokyo</td></tr>
</table>

Appendix - 3 List of Interviewee

(1) Government office in Saint Lucia

1) Ministry of Agriculture, Fisheries, Physical Planning, Natural Resources and Co-operatives

Hon. Ezechiel Junior Joseph	Minister

2) Ministry of Commerce, Industry, Enterprise Development and Consumer Affairs

Hon. Bradley Felix	Minister

3) Department of Fisheries

Ms. Sarita Williams-Peter	Chief Fisheries Officer
Ms. Margaret Rita Straughn	Fisheries Extension Officer

(2) Choiseul fishing port

1) Choiseul Fishermen's Co-operative

Mr. Sextus Ancelatus Joinville	Representative

2) Local Community

Mr. Devon Shirron Stephen	Representative

(3) Private companies

1) C. O. Williams (Contactor)

Mr. Stephen Shingleton-Smith	General Manager

2) Skelly Construction (Contactor)

Mr. Robert Gajadhar	Managing Director

3) Overseas Engineering & Construction Co., Ltda. S. A. (Contactor)

Mr. Arthur S. R. Ling	Vice General Manager, Saint Lucia Branch Office
Mr. Charlie Chao	Project Manager, Saint Lucia Branch Office

4) Saiwak Construction (Contactor)

Mr. Alvin Saiwak	Managing Director

(4) Japanese parties

1) Embassy of Japan in Trinidad and Tobago

Tatsuo HIRAYAMA	Ambassador

2) JICA Saint Lucia office

Tsutomu KOBAYASHI	Chief Representative
Katsutaka KIKKAWA	Project Formulation Advisor

Appendix - 4 Minutes of Disscussion (M/D)
(1) First phase (date of signing: Nov. 16, 2017)

MINUTES OF MEETINGS
ON
DATA COLLECTION SURVEY ON CURRENT SITUATION
OF
THE PROJECT FOR IMPROVEMENT OF COASTAL FISHERIES DEVELOPMENT IN SAINT LUCIA
BETWEEN
MINISTRY OF AGRICULTURE, FISHERIES, PHYSICAL PLANNING, NATURAL RESOURCES AND CO-OPERATIVES, SAINT LUCIA
AND
JAPAN INTERNATIONAL COOPERATION AGENCY

Japan International Cooperation Agency (hereinafter referred to as "JICA") sent to Saint Lucia the Data Collection Survey Team (hereinafter referred to as "the Team"), which was headed by Mr. Kazuya SUZUKI who stayed in the country from 13 to 16 November, 2017.

The Team held a series of discussions on the Data Collection Survey on Current Situation of the Project for Improvement of Coastal Fisheries Development in Saint Lucia (hereinafter referred to as "the Survey") and related issues with the Ministry of Agriculture, Fisheries, Physical Planning, Natural Resources and Co-operatives (hereinafter referred to as "MOAF&C").

As a result of discussions and the field survey, JICA and MOAF&C hereby confirmed the main points mentioned in the attached document.

Date: November 16, 2017
Place: Castries, Saint Lucia

Mr. Kazuya SUZUKI
Leader
Data Collection Survey Team
Japan International Cooperation Agency (JICA)

Mr. John Calixte
Permanent Secretary
Department of Agriculture, Fisheries, Natural Resources and Co-operatives
Ministry of Agriculture, Fisheries, Physical Planning, Natural Resources and Co-operatives, Saint Lucia

ATTACHMENT

1. Objective of the Survey

Based on the result of the Confirmation Survey in March 2017, the Survey was decided to be conducted.

The objectives of the Survey are as follows;

- To collect necessary data and information such as the Comprehension of port shape, physical processes, current status and Natural Conditions (through Field inspection, Topographic survey, Bathymetric survey, Sediment survey, Meteorological survey, Oceanographic survey etc.) to consider possible countermeasures for recovery and / or improvement of the function of Choiseul Fishing Port (hereinafter referred to as "the Countermeasures"), which was constructed under the Japanese grant aid scheme in 2003;
- To investigate the Countermeasures based on the result of the above mentioned data and information.

The Team explained the details of the Survey such as Schedule of the Survey, Scope of Works, Survey Report etc. based on the Inception Report. Both sides discussed, modified part of the Inception Report and agreed.

2. Schedule of the Survey

The Survey will be consisted of two (2) Phases and carried out in accordance with the tentative schedule as below. The schedule is tentative and subject to change when both sides agree upon any necessity that will arise during the course of the Survey such as major storm.

-Phase 1:

(1) Preparation for the Survey and work in Japan for 1st Site Works in Saint Lucia (half (1/2) month)

(2) 1st Site Works in Saint Lucia (one and half (1.5) months)

(3) Works in Japan for analysis of 1st Site Works and preparation of 2nd Site Works in Saint Lucia (seven (7) months)

(4) Explanation of main points of Progress Report 1 and submission of primary data to Saint Lucia side and 2nd Site Works in Saint Lucia (one and half (1.5) months)

(5) Works in Japan for analysis of 2nd Site Works in Saint Lucia (seven (7) months)

(6) Explanation of Progress Report 2 to Saint Lucia side

-Phase 2:

(1) Works in Japan based on the result of the Phase 1 and preparation of 3rd Site Works in Saint Lucia for Draft final report (eight and half (8.5) months)

(2) 3rd Site Works in Saint Lucia for explanation and confirmation of Draft final report (half (0.5) month)

(3) Works in Japan to finalize final report (one (1) month)

(4) Submit final report to Saint Lucia side

Tentative Survey Schedule

【Phase 1】

Year	2017				2018												2019			
Month	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4
Work in Japan																				
Work in SL																				

【Phase 2】

Year	2019								2020		
Month	5	6	7	8	9	10	11	12	1	2	3
Work in Japan											
Work in SL											

3. Scope of Works

Both sides confirmed that the Survey would be implemented based on "4. Execution of the Study" in the Inception Report from page 4 to page 18.

4. Survey Report

The Team will prepare and submit the following reports in English to the Saint Lucia side.

4.1. Inception Report

To be submitted at the commencement of the 1st site works period in Saint Lucia. The report contains the schedule and method of the Survey.

4.2. Copy of slide presentation of main points of Progress Report 1 and primary data

To be submitted at the beginning 2nd Site Works.

4.3. Progress Report 2

To be submitted at the end of the Phase 1.

4.4. Draft Final Report

To be submitted at the commencement of the 3rd Site Works period in Saint Lucia.

4.5. Final Report

To be submitted at the end of the phase 2.

5. Undertakings of the Government of the Saint Lucia

The Team requested to the Saint Lucia side as following matters;

- MOAF&C would act as a counterpart agency to the Team and also coordinate among organizations concerned for the smooth implementation of the Survey;
- MOAF&C would, at its own expense, provide the Team with the following items in cooperation with other government organizations concerned;
  1) Data and information related;
  2) Counterpart personnel;
  3) Entry permits necessary for the Team; and
  4) Support in obtaining other privileges and benefits if necessary.
- MOAF&C also would support the Team as follows;
  1) Smooth custom clearance procedures for survey equipment and others during the Survey;
  2) Approval on survey, access and shooting photography for the site works at the fishing ports and water area by the Team;
  3) Counterpart accompanying the site works; and
  4) Permission for taking test specimen out of the country by the Team.
- MOAF&C will not facilitate any payment of works done by the Team or sub contractors that the Team may hire for works. The Team is solely responsible for all survey works and any other works needed to carry out to collect data.

6. Other relevant issues

6.1. Basic idea for recovery and-or improvement of function of Choiseul Fishing Port

The Team explained again that the basic idea of the Countermeasures is eliminating sedimentation on the premise so that the existing maritime structures can be effectively utilized. The following points were explained again MOAF&C and MOAF&C understood;

- It will take about 2 years to commence countermeasure works for implementing the Study and Preparatory Survey, etc.;

- Even if countermeasure works are implemented, the maintenance and operation activities such as dredging sedimentation may be necessary and these activities are required to be continuous basis;
- The scale of countermeasure works is subject to the approval of the Government of Japan and should be less than the original cost of the Project;
- In case the Japanese side decides that implementation of countermeasure works is not effective based on above basic idea as a result of the Survey or Preparatory Survey, the basic idea of the Countermeasures will consider other options such as removal of maritime structures, reclamation of existing wharf, construction of maritime structures of pier and slip way and etc..

6.2. Dredging works at Choiseul Fishing Port

The Saint Lucia side strongly requested the support of Japan side to clear the port entrance for provisional use during the Survey period as this was the understanding of Saint Lucia side at the diplomatic level. The Team explained to the Saint Lucia side that dredging works are not included in the Survey activities. The Team will convey the request from Saint Lucia side to appropriate authorities.

6.3. Survey period

The Saint Lucia side requested that the 2nd Works in Japan and phase 2 should be shortened. The Team will respond to this request at the end of March 2018.

6.4. Geotechnical Surveys of soil/sand

The Saint Lucia side requested that Geotechnical Surveys of soil/sand particles be included in the Survey to determine origin of sedimentation at the port. The Team agreed to include it in the Sediment survey.

Annex-1: Inception Report
Annex-2: Presentation material

(2) Second phase (date of signing: Jan. 30, 2020)

MINUTES OF DISCUSSIONS
ON
DATA COLLECTION SURVEY ON CURRENT SITUATION
OF
THE PROJECT FOR IMPROVEMENT OF COASTAL FISHERIES DEVELOPMENT IN SAINT LUCIA
BETWEEN
MINISTRY OF AGRICULTURE, FISHERIES, PHYSICAL PLANNING, NATURAL RESOURCES AND CO-OPERATIVES, SAINT LUCIA
AND
JAPAN INTERNATIONAL COOPERATION AGENCY

With reference to the Minutes of Meetings on "the Data Collection Survey on Current Situation of the Project for Improvement of Coastal Fisheries Development in Saint Lucia" (hereinafter referred to as "the Survey") signed between the Ministry of Agriculture, Fisheries, Physical Planning, Natural Resources and Co-operatives (hereinafter referred to as " MOAF&C ") and Japan International Cooperation Agency (hereinafter referred to as "JICA") on November 16, 2017, JICA sent to Saint Lucia the Survey Team headed by Mr. Kazuya SUZUKI who stayed from 25th January to 30th January, 2020 for the explanation of the Draft Final Report of the Survey (hereinafter referred to as "the Draft Report").

The Survey Team held a series of discussions on the Draft Report and related issues with MOAF&C.

As a result of discussions, JICA and MOAF&C hereby confirmed the main points mentioned in the attached document.

Date: 30th January, 2020
Place: Castries, Saint Lucia

Mr. Tsutomu KOBAYASHI
Chief Representative
Saint Lucia Office
Japan International Cooperation Agency
(JICA)

Hon. Ezechiel JOSEPH
Minister for Agriculture, Fisheries, Physical Planning, Natural Resources and Co-operatives
SAINT LUCIA

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ATTACHMENT

1. Progress of the Survey

Based on the Minutes of Meetings signed on November 16, 2017, JICA has and will conduct the Survey from November 2017 to March 2020 for the purpose of collecting necessary data and information to consider possible countermeasures for recovery and/or improvement of the function of Choiseul Fishing Port, which was constructed under the Japanese grant scheme in 2003.

In the Phase one (1) of the Survey, it was conducted by the statistical analysis of the wave data, wave hindcasting and improvement of its accuracy, wave numerical simulation. Then the sand sedimentation model was developed and the effective countermeasures were recommended based on the result of the simulation.

In the Phase two (2), hydraulic model tests were conducted to verify the effectiveness of the countermeasures. The results of the test, the effectiveness of countermeasures mainly consisting of the second groin and submerged breakwater were confirmed in December 2019 and the findings were compiled in the Draft Report in January 2020.

2. Contents of the Draft Report and countermeasures for recovery and/or improvement of function of Choiseul Fishing Port

The Survey Team submitted the Draft Report to MOAF&C and MOAF&C received it. After the explanation of the contents of the Draft Report by the Survey Team and a series of discussions between both sides, the MOAF&C (Saint Lucia side) indicated their intention to promote the implementation of the countermeasures proposed by the Survey team which were detailed in the Draft Report.

3. Submission of proposal for the implementation of Japanese grant aid Project.

MOAF&C (Saint Lucia side) indicated that they would request Japan to cooperate on the implementation of countermeasures for sediment control in a grant aid project based on the Draft Report. The Team explained that the submission of an official proposal by the government of Saint Lucia to the government of Japan is needed through the diplomatic route. The proposal must be reviewed by the government of Japan and be adopted by the cabinet meeting.

MOAF&C (Saint Lucia side) promised to prepare and submit the proposal to the government of Japan.

4. Emergency measures (Short-term measures)

MOAF&C (Saint Lucia side) strongly requested short-term measures for keeping the functioning of the Choiseul Fishing Port before completion of the Japanese grant aid Project, which will take two and half years until the completion of the countermeasures works.

The Survey team explained that JICA would convey the need for the continuation of use of the Choiseul Fishing Port before completion of the Japanese grant aid Project through continuous dredging of the port, as needed, to the Ministry of Foreign Affairs in Japan.

5. Necessity of continuous dredging works for maintenance

The effect of proposed countermeasures works is expected to significantly reduce the amount of sedimentation in and around the Choiseul Fishing Port. Also it will reduce the frequency of dredging. However, sediment does not stop at all and even in Japan's experience, dredging for maintenance is required more than once a year at many fishing ports in Japan. Further, the proposed countermeasures are designed under normal weather conditions. If sedimentation occurs due to a natural disaster such as a hurricane, dredging will be required separately from the regular works.

MOAF&C (Saint Lucia side) understood that even after the completion of the countermeasures works, it may be necessary to continue the regular and appropriate dredging work for maintenance about once per year, and confirmed the implementation of the dredging work by the Saint Lucia side, if required.

6. Others

i. The Survey Team explained that a monitoring method would be introduced when countermeasures works for improvement of Choiseul Fishing Port would be implemented by Japanese grant aid project.
ii. The Survey Team explained that JICA will consider options for appropriate machinery for Saint Lucia side to engage in maintenance dredging and will provide the information to the MOAF&C to be included in the proposal submission for Japanese grant aid project for the implementation of countermeasures for sedimentation control.
iii. During monitoring period, Japanese side will adjust the initial installation position, direction and size (length, level, etc.) of the submerged breakwater and the second groin according to the monitoring results and will perform the additional collection works. MOAF&C concurred that these methods would make the countermeasures more effective. The Survey Team stated that JICA

would consider details and possibility of these methods in the preparatory survey.

iv. JICA is also considering the possibility of utilizing companies, which have good experiences and are registered in Saint Lucia or neighbouring countries, as contractors in the grant aid project. MOAF&C agreed to JICA's consideration and would support to sharing necessary information. MOAF&C promised to share necessary information on the government's procurement regime to JICA.

Annex-1: Draft Final Report
Annex-2: Presentation material