6.1.2 Seaside Capacity (Navigation and Berthing)

According to the results of the simulation, in the berth allocation conditions shown in Table 6.1.1 the resulting seaside service level in 2022 is 5.7% for annual cargo throughputs of 24 million tons of conventional cargo and 784,000 TEUs of containers, which satisfies the criterion of 10%. In other words, saturation of the Port where it reaches its capacity will come after the year 2022.

On the other hand, if any one berth is reduced from the berth allocation conditions shown in Table 6.1.1, the port shows over capacity conditions, viz. saturation. As a sample, if the number of multi-purpose berths is reduced to one from two, the resulting seaside service level jumps to 40.9% far exceeding 10% level where considerable number of off-shore waiting ships is observed due to port congestion (see Figure 6.1.2).

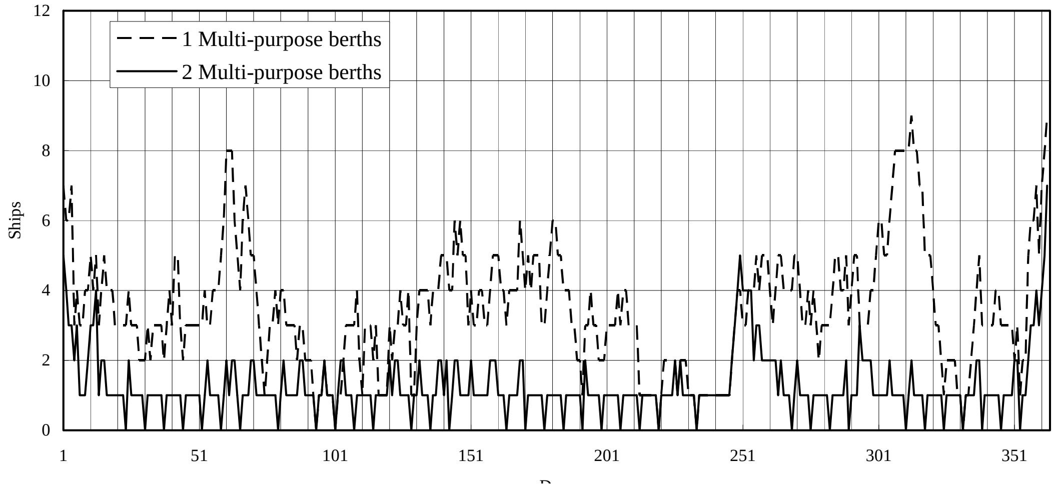


Figure 6.1.2 Number of Offshore Waiting Ships at Pecem Port

6.1.3 Landside Capacity (Storage and Railway Access)

(1) Storage

By using the simulation model, the storage capacities required in 2022 have been estimated by cargo item, and have been compared with the existing storage capacities, if they exist (see Table 6.1.2).

Containers

To estimate required container stacking capacities, the following conditions have been used:

- Arrival and leaving pattern of containers from/to the hinterland (see Figure 6.1.3)

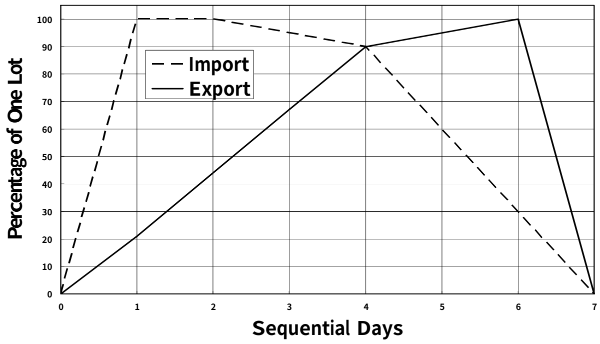


Figure 6.1.3 Arrival and Leaving Pattern of Containers

- Percentage of CFS cargoes:
    - Export: 3%
    - Import: 10%

Container ship arrival schedule is assumed on the basis of weekly services by shipping routes comprising the following routes referring to the current actual schedule:

- USA East Coast
- USA Gulf
- EU North Seas
- EU Mediterranean
- Feeder

The resulting fluctuation of container number dwelling at a container stacking yard is shown in Figure 6.1.4.

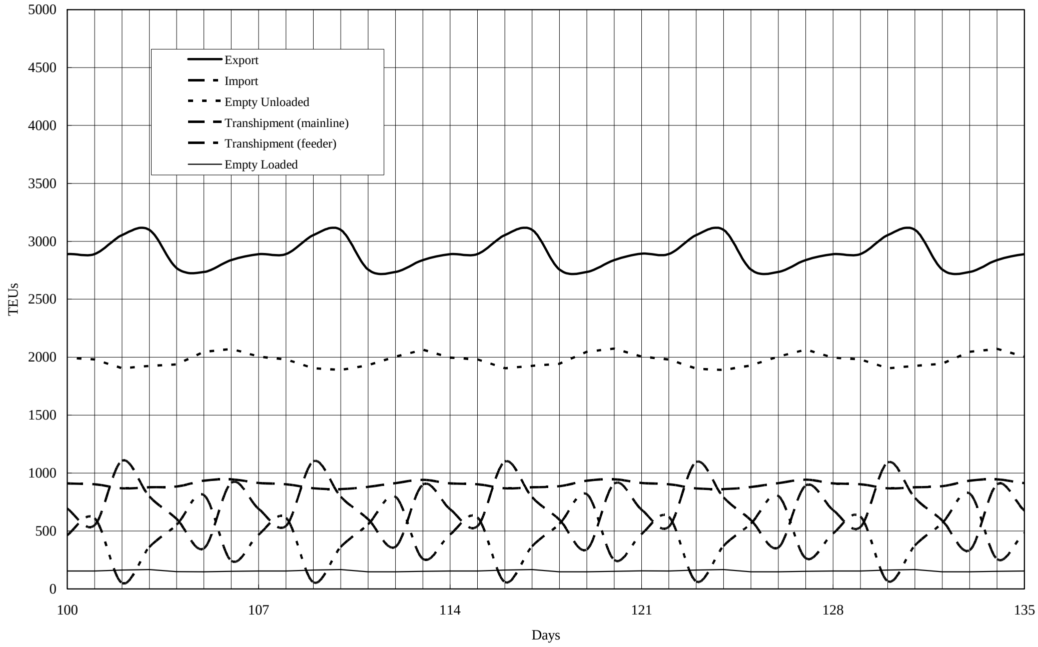


Figure 6.1.4 Number of Containers Dwelling at Container Stacking Yard

According to the result of the simulation, the required container stacking capacities and the corresponding ground slots (loss parameter: 1.25) assuming RTG system by container category have been computed as follows:

Container Category	Required Capacity (TEUs)	Tiers	Required Ground Slots
Export (Laden)	3,099	3.8	1,019
Import (Laden)	947	3.5	338
Transhipment (main line)	1,107	3.8	364
Transhipment (Feeder)	824	3.8	271
Empty (unloaded)	2074	4.0	648
Empty (loaded)	167	4.0	52
	8,218		2,692

As shown above, in 2022, the required container stacking capacity and ground slots are estimated as 8,200 and 2,700 in terms of TEUs, respectively.

On the other hand, current container stacking capacity at Pecem Port is around 8,900 TEUs. Taking account of "Loss Parameter" mentioned above to estimate actual require capacity to cope with different shipping line services, actual capacity is estimated as approximately 7,100 TEUs in the current container-handling system using reach-stackers. By 2022, however, the open yard for general cargo storage temporarily used for container stacking as shown in the table below, viz. A – F, and R – U, needs to be surrendered for the storage of steel products mainly of thick slabs. By deducting that capacity, actual container stacking capacity is estimated as around 4,500 TEUs (5,643 TEUs/1.25).

Thus, by comparing with the required capacity of around 8,200 TEUs in 2022 as mentioned above, the container stacking capacity needs to be increased by the preparation of new stacking yard and/or introduction of new container –stacking system, viz. RTG system.

Table 6.1.2 Current Container Stacking Capacity at Pecem Port

Unit: TEUs

Block No.	Type	Blocks	Rows	Bays	Ground Slots	Tiers	Stacking .Capacity
G	Reefer	1	4	22	88	2	176
H	Reefer	1	4	22	88	2	176
I	Reefer	1	4	22	88	2	176
J	Reefer	1	4	22	88	2	176
K	Reefer	1	4	22	88	2	176
L	Reefer	1	4	22	88	2	176
				Reefer	528		1056
M	Empty	1	5	33	165	4	660
N	Empty	1	10	33	330	4	1,320
O	Empty	1	10	33	330	4	1,320
P	Dry	1	8	33	264	3	792
Q	Dry	1	5	33	165	3	495
				Dry	1,254		4,587
Capacity on the Container Yard					1,782		5,643
A	Dry	2	2	20	80	3	240
B	Dry	2	2	21	84	3	252
C	Dry	2	3	20	120	3	360
D	Dry	2	3	21	126	3	378
E	Dry	3	2	20	120	3	360
F	Dry	3	2	21	126	3	378
General Cargo -R	Dry	1	5	11	55	3	165
General Cargo -S	Dry	1	10	11	110	3	330
General Cargo -T	Dry	1	10	11	110	3	330
General Cargo -U	Dry	1	8	11	88	3	264
General Cargo	Dangerous	1	5	22	110	2	220
Capacity on the General Cargo Yard				Dry	1,129		3,277
Total Stacking Capacity					2,911		8,920

Source: Ceara Port

<u>Break-bulk Cargoes</u>

The following conditions have been used so as to estimate required storage capacities of break-bulk cargoes such as steel products, palletized fresh fruits in carton, bagged cement:

- Arrival and leaving pattern of the cargoes from/to the hinterland (see Figure 6.1.5)

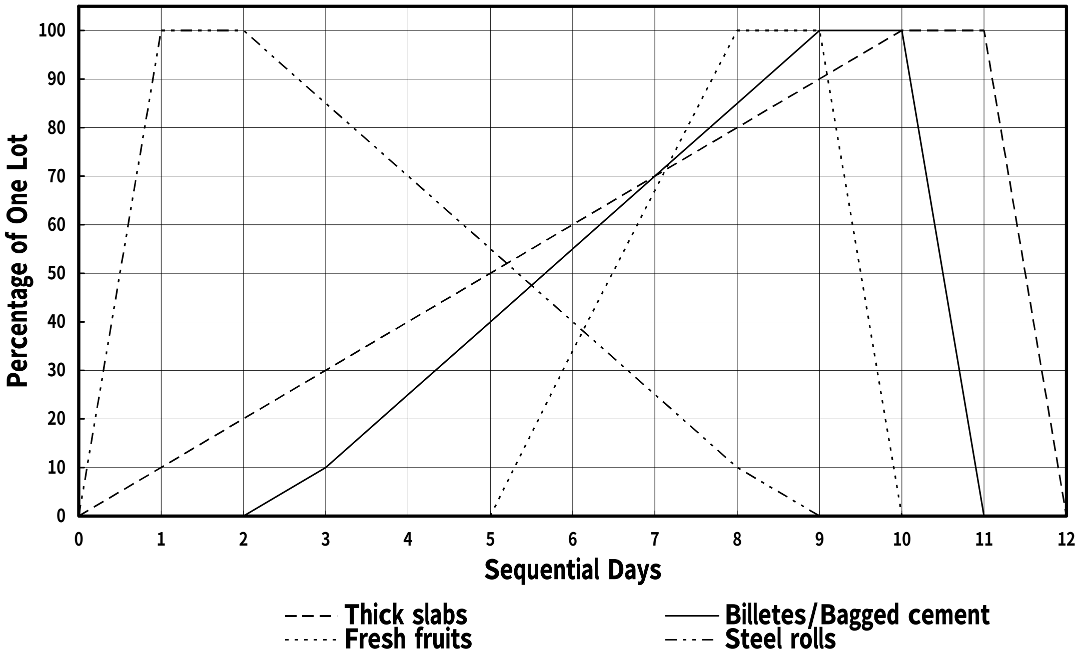


Figure 6.1.5 Arrival and Leaving Pattern of Break-bulk Cargoes

- Storage type and floor storage unit

Cargo Item	Storage type	Tiers	Floor unit (tons/sq. m)
Thick slabs	Open yard	4	5.8
Steel rolls	Shed	1	4.0
Steel billets	Open yard	3	3.7
Bagged cement	Shed	3	6.2
Fresh fruits	Cold storage	3	2.5

The resulting fluctuation of the required areas of open yards and transit sheds in 2022 is shown in Figure 6.1.6.

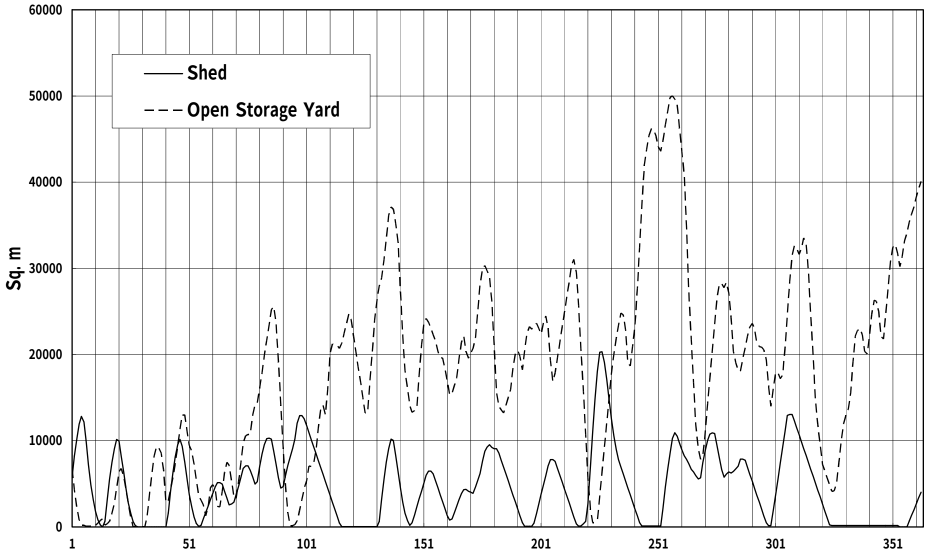


Figure 6.1.6 Required Areas of Open Yards and Transit Sheds

According to the result of the simulation shown in the above figure, the required storage areas in the consideration of loss parameter (1.25) are summarized below:

Type of storage	Area (sq. m)
Open yard	62,000
Transit shed	24,500

As to open storage, the existing yard of 100,000 sq. m will be sufficient for the required area indicated above in 2022. On the other hand, as to transit sheds, 15,000 sq. m of the existing floor space will be insufficient in 2022 both for conventional cargo storage and CFS. Assuming the existing floor space of 3,000 sq. m is allocated for CFS, new transit sheds with total floor space of 12,500 sq. m need to be prepared in 2022.

Dry Bulk Cargoes

The following conditions have been used so as to estimate required storage capacities of bulk cargoes comprising soybeans, fertilizer and cokes:

- Arrival and leaving pattern of the cargoes from/to the hinterland

  It has been assumed that the above dry bulk cargoes will be brought into the Port by block train with the same pattern as thick slabs (see Figure 6.1.4).

- Storage type

Cargo Item	Storage type
Soybeans	Silos
Fertilizer	Horizontal warehouse
Cokes	Stockpiles

The resulting fluctuation of the required storage capacities in 2022 is shown in Figure 6.1.7.

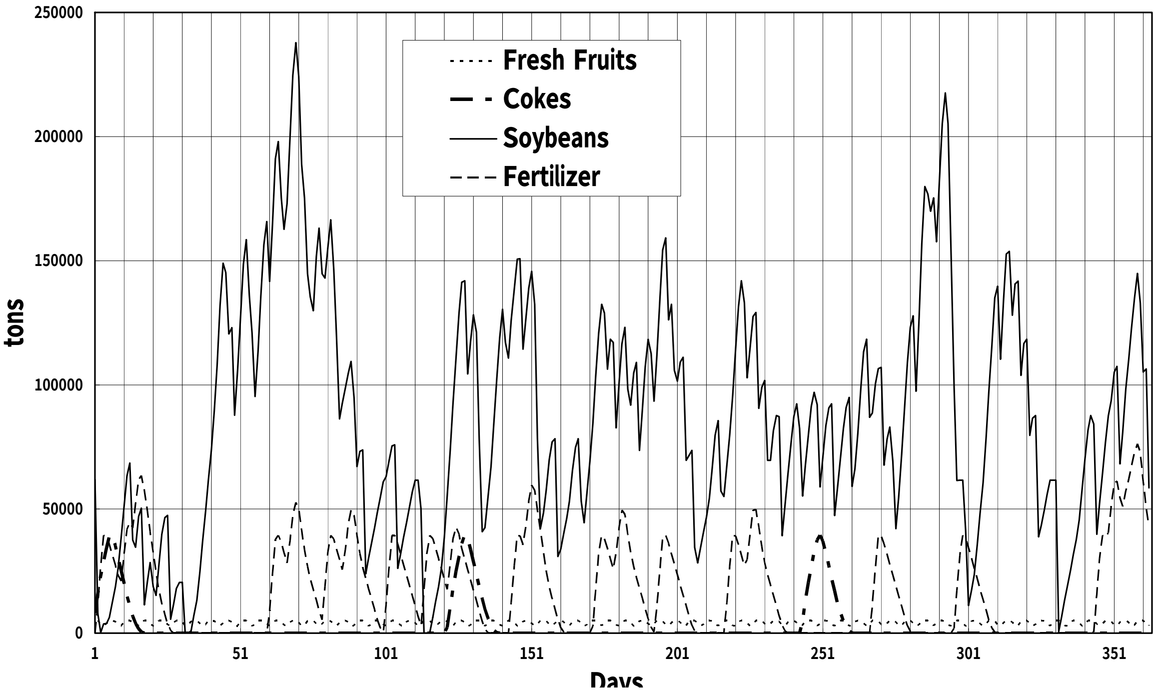


Figure 6.1.7 Required Storage Capacities of Dry Bulk Cargoes

From the above, the storage capacities additionally required by 2022 are summarized in table 6.1.3.

Table 6.1.3 Summary of Required Storage Capacities in 2022 at Pecem Port

Stored Cargo		Storage capacity				Additionally required storage area (sq.m)
Category	Annual throughput ('000 tons/TEUs)	Unit	Existing	Required	Balance	
Cokes	200	tons	0	39,418	-39,418	18,200
Soybeans	4,500	tons	0	237,791	-237,791	13,895
Fertilizers	1,000	tons	0	76,213	-76,213	8,917
Break-bulk cargo	3,570	sq. m (open yard)	100,000	62,045	37,955	-
		sq. m (shed)	12,000	24,495	-12,495	12,495
Fresh Fruits	327	tons	0	5,031	-5,031	5,509
Containers （Yard)	706	TEUs （yard)	4,200	8,200	-4,000	-
		tons （CFS)	3,000	2,887	113	-

(2) Railway Access

The existing railway sidings are placed in front of the existing warehouses No.1 and No. 2. These sidings are only usable for break-bulk cargoes brought into/out of the warehouses. Thus, sidings having accesses to soybean silos, fertilizer warehouses, cokes stockpiles, and the container yard need to be newly installed to be diverted from the existing access railway line.

6.2 Port Improvement Plan of the Existing Facilities

6.2.1 Extension of the Existing Breakwater

It has been proposed to extend the existing west breakwater by 300 m to reduce sea wave (swell) agitation in front of Pier No.1. By the extension, calmness level in the basin will be improved by an increase in 50 cm non-excess provability of wave height to 95.8% from the current level of 89.7% at the tip of the pier (see Section 6.5).

6.3 Port Expansion Plan

6.3.1 Necessity of Port Expansion

To meet the forecast demand for increase in cargo-handling capacity in the stage of the Long-Term Plan with the target year 2022, it is necessary to expand port capacity. The new off-shore port area needs to be placed to the east of the existing off-shore port area so as to facilitate an access from the reserved land port area to be used in the future extending to the east from the existing land port area, whereas to the west of the existing port area, Pecem Village is located, and if expanded in that direction, there would be a fear of interference between off-shore port operations at the existing and newly expanded areas.

In addition to the demand for a quantitative increase in cargo-handling capacity, it is required to increase the competitiveness of the Port among the neighbouring ports in the northeast region by preparing highly efficient marine terminals with deepwater berths catering for Post-Panamax container ship, Cape-Size bulkers and Aframax tankers connected with well-designed railway access lines as well as road access.

6.3.2 Marine Terminals

The required number, scale and type of marine terminals at the expanded port area have been verified by computer simulation. In the first step, some number, scale and type of terminals have been assumed, and then has been verified whether the required service level has been satisfied. If not satisfied, different figures have been given for the further simulation trial. After trial and error procedure, eventually, the optimum number, scale and type of required marine terminals have been determined composed of four terminals (Container Terminal, Grain Terminal, Multi-purpose Terminal, and Fruits Terminal) as shown below.

(1) Off-shore Container Terminal

An off-shore container terminal is planned. The principal dimensions of the design container ship of Post-Panamax type are:

- Laden capacity: 9,200 TEUs
- LOA: 347 m
- Summer draft: 14.5 m
- Moulded breadth: 46 m

There are two main purposes in preparing a full-scale off-shore container terminal. One is to surrender Pier 1 to the handling of iron ore pellets and steel products after the start of steel mill operations. The other is to improve container handling efficiency by preparing container gantry cranes and shortening hauling distance between dockside and container stacking yard, and to upgrade operational service level of reefer container handling by preparing reefer plugs close to on-dock.

Main facilities and equipment (see Section 6.3.6) are:

- Berth

  Length: 900 m

  Water depth: 16 m
- Quayside container gantry cranes

  Number of units: 6

  Out reach: 50 m (18 rows)

  Back reach: 16m

  Rail span: 30 m
- RTG (Rubber Tired Gantry Cranes)

  Number of units: 15

  Specification: 4 high 5 over type

  Rail span: 23.47 m
- Terminal Area

Length alongside: 980 m

Width: 300 m

Area: 29.4 ha

- Apron Area

  Length alongside: 900 m

  Width: 57 m

  Area: 5.1 ha

- Container stacking yard

  Length alongside: 900 m

  Width: 243 m

  Area: 21.9 ha

  Ground slots: 5,544 TEUs

  Dry containers: 4,680 TEUs

  Reefer containers: 864 TEUs

  Stacking capacity: 21,312 TEUs

  Dry containers: 18,720 TEUs

  Reefer containers: 2,592 TEUs

  Reefer plugs: 1,296 Units

(2) Grain/Fertilizer Terminals

It is planned to prepare a grain/fertilizer terminals composed of an off-shore berth in the east of the exiting south breakwater and silos (soybeans) and horizontal warehouse (fertilizer) to be placed on land area presently reserved for the future port use.

The principal dimensions of the design bulker of Cape-size type for grains are:

- 114,000 DWT
- LOA: 266 m
- Summer draft: 14.5 m
- Moulded breadth: 40.6 m

The principal dimensions of the design bulker of Handy-size type for fertilizers are:

- 45,000 DWT
- LOA: 186 m
- Summer draft: 11.0 m
- Moulded breadth: 30.4m

Main facilities and equipment (see Section 6.3.6) are:

- Berth

Length: 320 m

Water depth: 16 m

- Ship-loaders and unloaders (multi-function cranes)

  Number of units: 2

  Ship loaders: Rated capacity: 2,500 tons per hour per unit

  Ship unloaders (mechanical type): Rated capacity: 700 tons per hour per unit

  Rail span: 12 m

- Silos for grains

  Storage capacity: 230,000 tons

  Length: 325 m

  Width: 42.8 m

- Horizontal warehouse for fertilizers

  Storage capacity: 76,000 tons

  Length: 200 m

  Width: 45 m

- Belt conveyors

  Number of lines: 2

  Capacity: 2,500 tons per hour per line

  Type: flat or tubular

- Railway wagon receiving facilities

  Number of lines: 2

- Railway tracks

  Number of tracks: 8

(3) Off-shore Multi-purpose Terminal

It is planned to prepare an off-shore multi-purpose terminal equipped with transit sheds just behind its berths. The principal dimensions of the design bulker of Handy-size type for steel products, etc. are:

- 45,000 DWT
- LOA: 186 m
- Summer draft: 11.0 m
- Moulded breadth: 30.4m

There are two main purposes in preparing an off-shore multi-purpose terminal. One is to receive break-bulk cargoes such as steel products overflowed from Pier 1 The other is to improve break-bulk handling efficiency by the preparation of transit sheds behind berths within the manoeuvring distance of forklift trucks (15 m from berth face), consequently diminishing current double handling operations observed both on Pier 1 and the existing warehouse on land.

Main facilities are:

- Berth

  Length: 520 m

  Water depth: 16 m

- Transit sheds

  Number of sheds: 2

  Length: 150 m per unit

  Width: 50 m

  Floor space: 15,000 sq. m in total

(4) Off-shore Fruits Terminal

The only means to receive reefer ships is to prepare a terminal equipped with a cold storage just behind a berth. Thus, it is planned to prepare an off-shore fruits terminal. The principal dimensions of the design reefer ship are:

- 6,100 DWT
- LOA: 134 m
- Summer draft: 7.6 m
- Moulded breadth: 15.8 m

Main facilities are:

- Berth

  Length: 160 m

  Water depth: 16 m

- Cold storages

  Length: 110 m

  Width: 50 m

  Floor space: 5,500 sq. m

(5) Cokes Stockpiles

It is planned to prepare cokes stockpiles with the following dimensions:

- Stockpiles

  Storage capacity: 39,000 tons

  Length: 260 m

  Width: 70 m

  Area: 18,200 sq. m

6.3.3 Required Dimensions of a New Sea Channel and Basins

(1) Necessity of a New Sea Channel

To have access to a new off-shore port area to be expanded in the direction of the east, it is necessary to create an access channel. A one-way channel has been verified to be sufficient by the results of the simulation.

(2) Alignment

Taking account of the statistical wave directions off the Port, the channel direction of N0° has been judged adequate.

(3) Width

The bottom width of the planned one-way sea channel has been designed through the verification by applying the prevailing guidelines including PIANC for the representative principal dimensions of the design vessels. To design the access channel, ULCV (Ultra Large Container Vessel) with a breadth of 57 m (22 rows) and LOA of 381 m has been considered. According to the PIANC Guideline, the required channel width of 210 m has been estimated as follows:

- Basic Maneuvering lane:	1.5B per lane
- Bank Clearance:	0.5B per lane x 2
- Wave height:	0.5B per lane
- Cross wind:	0.2B per lane
- Aids to navigation:	0.1B per lane
- Bottom surface:	0.1B per lane
- Depth of waterway:	0.2B per lane
Total	3.6B (B = 57m)

On the other hand, according to the deviation angle method (angle = 15°, L = 381 m, B = 57 m) the required channel width is 211 m almost the same as the figure derived from the PIANC Guideline. Thus, in this study, 210 m has been applied as the planned bottom breadth of the sea channel

(4) Water Depth

The water depths of the planned one-way sea channel and basins within the expanded port area protected breakwaters have been designed by applying the prevailing guidelines including PIANC for the representative principal dimensions of the design vessels. According to the PIANC Guideline, water depth of 16 m is required by applying multiplier of 1.1 for design draft of 14.5 m in inside basins. On the other hand, water depths of 16.5 m in the open sea are required according to the method considering ship movements that was recently developed in Japan. The following components have been used in case of the sea channel.

- Draft:	14.5 m	
- Squat:	0.2 m	
- Pitching:	1.0 m	(wave height: 2.5 m as critical wave height in pilot service)
- Under keel clearance:	0.8 m	(5% of the draft)
Total	16.5 m	

(5) Turning Basin

The turning basin within the expanded port area protected breakwaters has been designed so as to provide a turning circle with a diameter of twice the LOA of the design vessel. The maximum length among design vessel is 381 m. Thus a diameter of 760 m for turning circle has been considered in the design of the turning basin.

(6) Basin for Port Service Boats

The basin for port service boats including tugboats, pilot boats and survey boats has been planned so as to keep required calmness for those small boats by placing the secondary breakwaters. The principal dimensions of the design boat are:

- LOA: 33 m
- Draft (from the bottom of propeller): 3.6 m
- Moulded breadth: 10 m
- Main engines: 4,200 HP in total

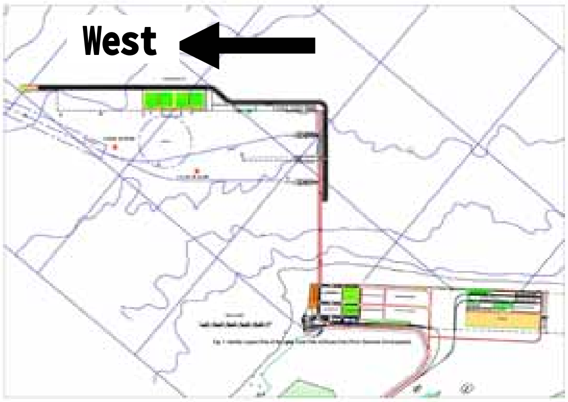
6.3.4 Required Breakwaters

Breakwaters are required for the new off-shore port area to protect the inner channel, turning basins and berths. The new breakwaters need to be placed so as to halt the waves in the outer sea penetrating to the port waters from ENE as wind waves and NE as swell.

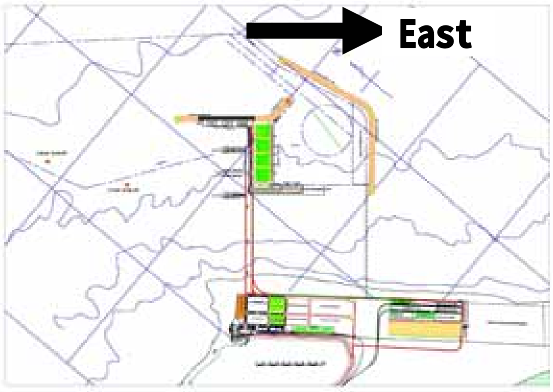
6.3.5 Facility Layout Plan

(1) Potential Directions of Port Expansion

When considering the direction of port expansion, the two directions, viz. east and west of the existing port facilities have been envisaged. The two options, viz. the west expansion option (Option 1) and the east expansion option (Option 2) have been compared in detail with possible layout plans as shown below.



Option 1



Option 2

As a result of the comparison, it has been concluded that the west expansion plan, “Option 1” has the following fatal disadvantages over the east expansion plan, “Option 2”:

- Insufficient protection of basins from the penetrating waves from ESE direction due to the limitation of extending the existing south breakwater.
- Excessively far haul distance from port land area for port cargo storage
- High construction cost

Thus, in this study, “Option 1” has been ruled out and “Option 2” has been further divided into four Alternatives which have been compared with each other to select the optimum plan as mentioned in the following Paragraph (2).

(2) Alternative Plans

Four alternative layout plans satisfying facility requirements for the new port in the stage of the Long-Term Plan mentioned in the Sections 6.3.2 – 6.3.4 have been made (see Figures 6.3.1 to 6.3.4). The main components of each alternative are shown in Table 6.3.1.

Table 6.3.1 Facility Components of Alternative Layout Plans

Component			Alternative - 1	Alternative - 2	Alternative - 3	Alternative - 4
Access channel		Bottom width (m)	210	210	210	210
		Water depth (m)	16.5	16.5	16.5	16.5
Basins		Water depth (m)	16	16	16	16
Breakwaters		Length (m)	3,400	3,400	3,400	3,680
Revetment		Length (m)	715	1,205	1,100	800
Marine Terminal	Container Terminal	Berth length (m)	900	900	900	900
		Water depth (m)	16	16	16	16
	Grain Terminal	Berth length (m)	320	320	320	320
		Water depth (m)	16	16	16	16
		Storage capacity ('000 tons)	230	230	230	230
	Multi-purpose Terminal	Berth length (m)	520	520	520	520
		Water depth (m)	16	16	16	16
		Sheds ('000sq. m)	15	15	15	15
	Fruits Terminal	Berth length (m)	160	160	160	160
		Water depth (m)	16	16	16	16
		Cold Storage('000sq. m)	5.5	5.5	5.5	5.5
Land use for expansion (ha)		Terminal area (off-shore)	37	23	37	39
		Terminal area (land)	80	96	80	80
		Total	117	119	117	119

Source: JICA Study Team

(3) Comparison of Alternative Facility Layout Plans

The above four alternatives have been compared with each other from the following points.

a) Calmness in the basin

Alternative-4 provide almost complete calmness against waves penetrating from the outer sea over the remaining alternatives.

b) Accessibility to the port terminals for railcars

In all the alternatives, cargo railcars are hauled directly to a railcar receiving station installed at each land terminal using the independent tracks diverted from an access railway line without any interference with each other.

c) Accessibility to the terminals for vehicles from the outside of the port

In all the alternatives, vehicles can access the land terminals along the planned port road without level crossing with railway tracks.

d) Required area for the port expansion

In Alternative-2, the expansion of container yard is planned mainly on the currently reserved area adjacent to the existing terminal. In contrast, in Alternative-1, Alternative-3 and Alternative-4, the expansion of container yard has been planned at off-shore artificial land. Thus, the total areas additionally required for the port expansion are almost the same in all the alternatives..

e) Conservation of the natural sand beach

All the alternatives have the similar breakwater layout plans, and hence the extent of possible impact on the natural sand beach in the proximity of the project site is considered almost the same. The anticipated phenomena are mentioned in Section 6.5.

f) Construction cost

Total construction cost indices of infra-structures of Alternatives 1 to 4 have been estimated as follows..

Table 6.3.2 Construction Cost Indices of Infrastructures of Alternatives

Alternative -1	Alternative -2	Alternative -3	Alternative - 4
100.0	100.7	101.7	99.8

It indicates that Alternative 4 is the most economical in initial investment.

g) Ease of further expansion

As to the ease of further expansion beyond the stage of the Long-Term Plan, Alternative-4 has an advantage over the remaining alternatives in that it can provide longer additoinal berth length as shown in the layout plans (future expandable area is indicated in dotted lines).

h) Accessibility to the marine terminals for calling vessels

All the alternatives give calling vessels safe access to the planned expanded port area through the straight sea channel. In addition, the stretch inside the port is protected from penetrating waves by breakwaters and gives sufficient stopping distance inside the port waters.

i) Competitiveness to other seaports in terms of water depth

All the alternatives give the Port competitiveness against the neighbouring seaports by preparing deepwater berths so as to receive large vessels.

j) Storage capacity

All the alternatives give sufficient storage areas essential for efficient terminal operations.

k) Efficiency of container-handling operations on dock

In Alternatives 1, 3 and 4, sufficient container stacking yard is lsituated just behind berths and hence, ensure efficient and swift container operations ondock. At contrast, Alternative-2, containers need to be hauled between dockside and container stacking yard placed on land yard through the long access brige. Thus, Alternative-2 has a disadvantage in iterms of operational efficiency.

On the other hand, as to break-bulk, and bulk cargo handling, all the Alternatives enable efficient and swift operaions ondock by the preparation of transit sheds just behind the berths or by the connection woth belt conveyors.

From the above comparison, Alternative-4 has been selected and proposed as the optimum plan.

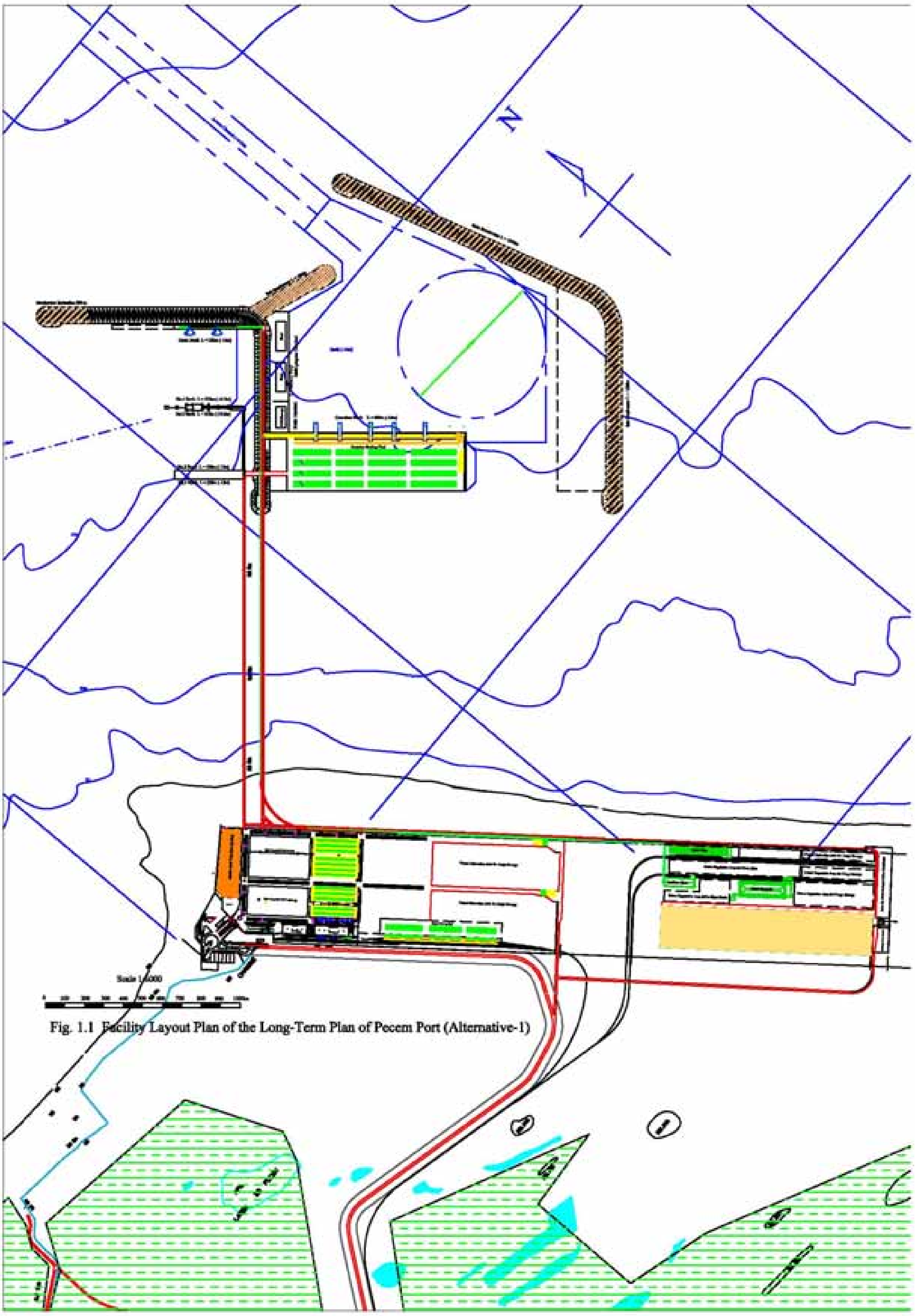


Figure 6.3.1 Facility Layout Plan in the Long-Term Plan (Alternative - 1)

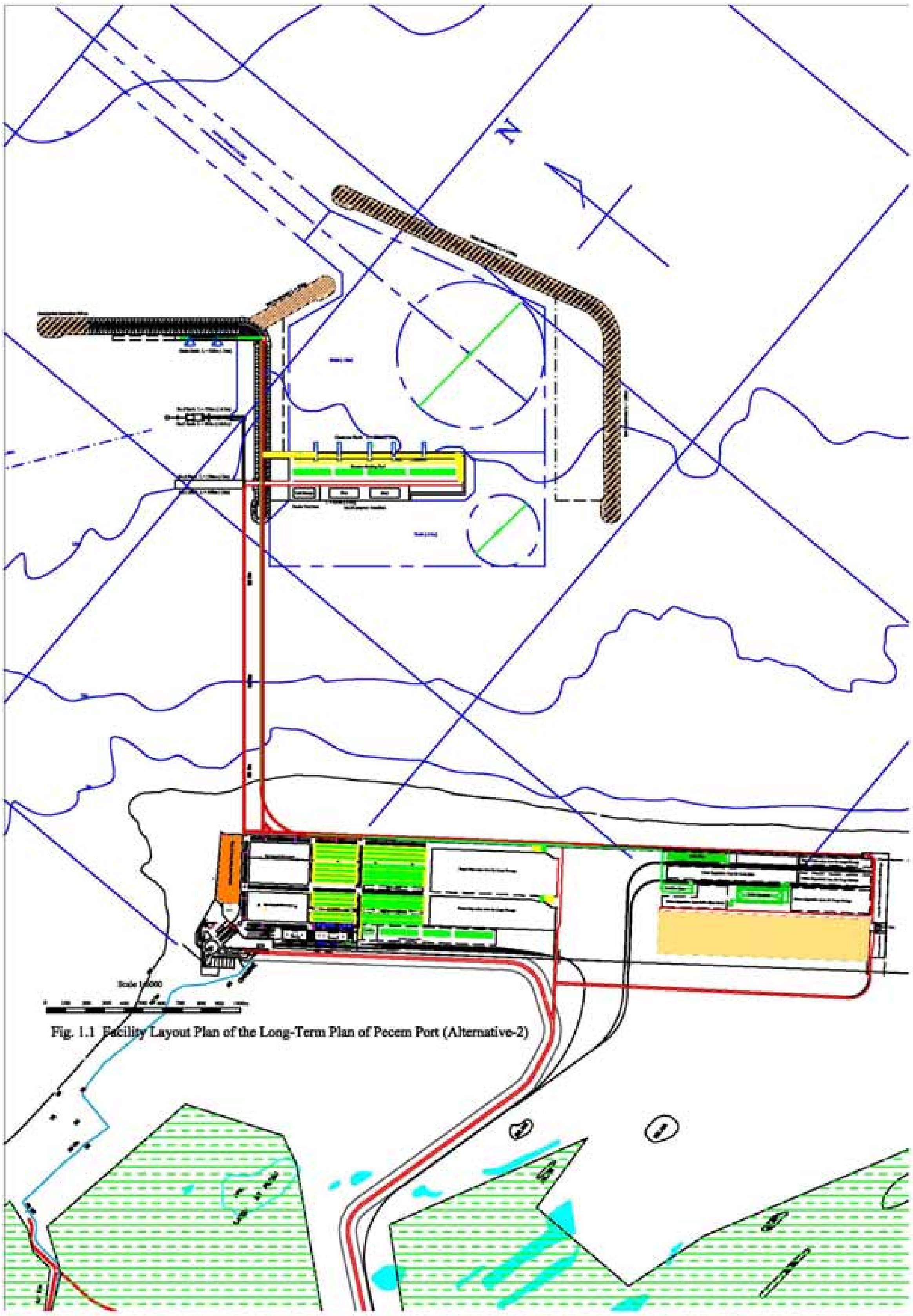


Figure 6.3.2 Facility Layout Plan in the Long-Term Plan (Alternative - 2)

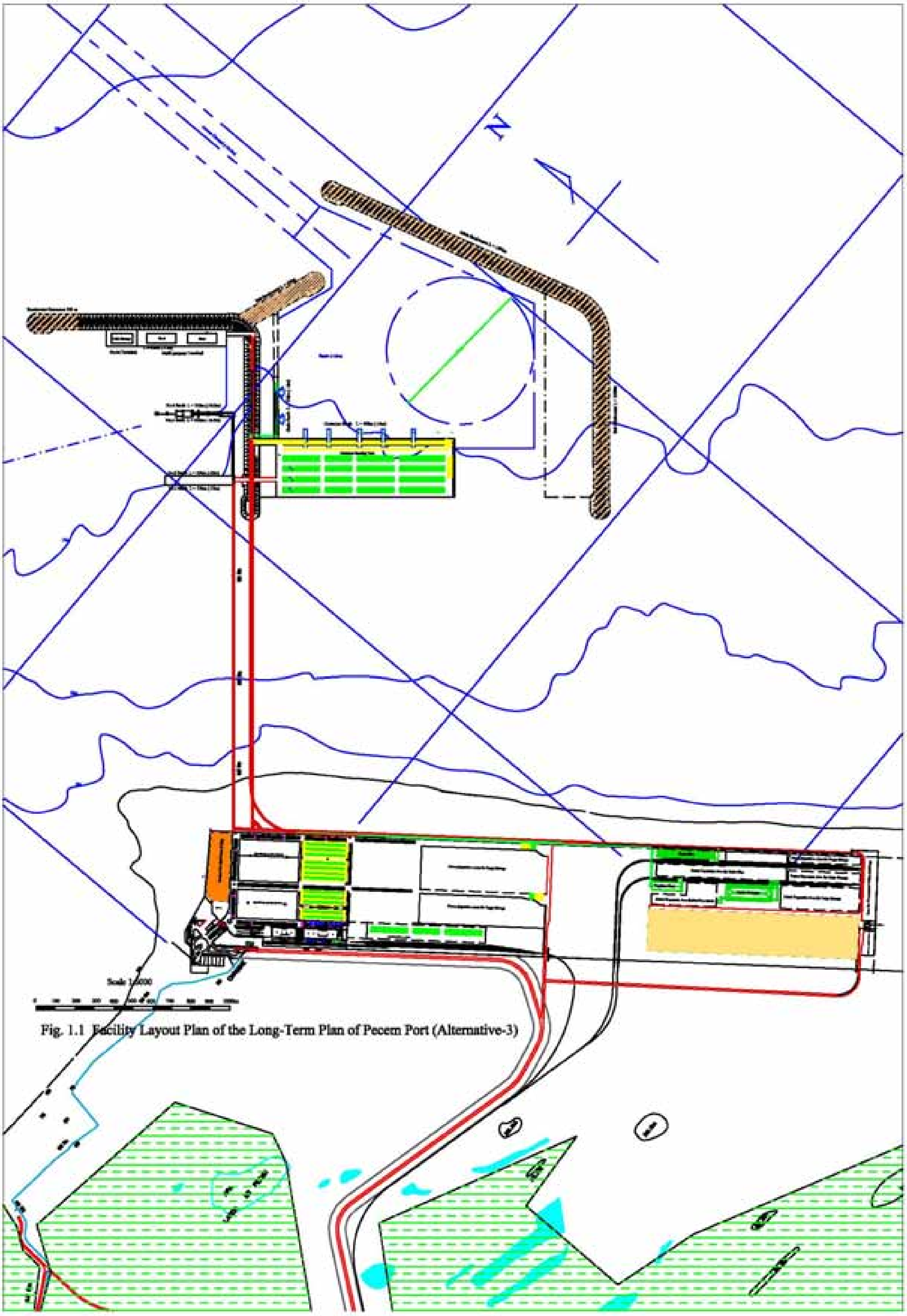


Figure 6.3.3 Facility Layout Plan in the Long-Term Plan (Alternative - 3)

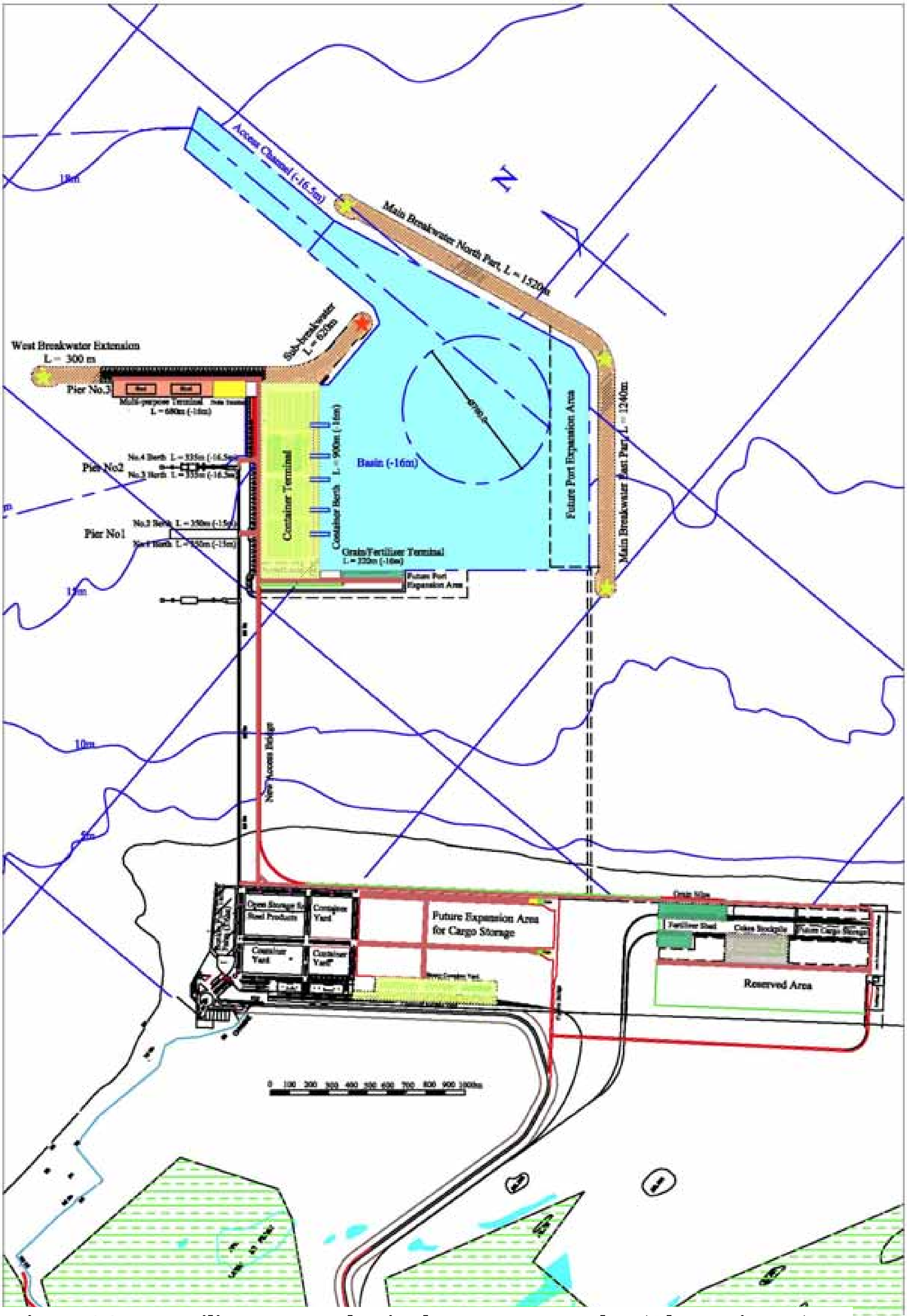


Figure 6.3.4 Facility Layout Plan in the Long-Term Plan (Alternative - 4)

6.3.6 Cargo Handling Systems

(1) Container Handling Operation System

1) Importance of Signal-Man's Role

Although efficiency of container operation depends largely on the skill or technique of a quay side crane operator, signal-man's role to support a crane operator is also very important for quick and smooth operation. A signal-man must consider the standing position to give signals to a crane operator. If signal-man's position is improper, the operator can not see the signal-man. To avoiding misunderstanding the meaning of signals, hand signals must be standardized and unified. Therefore, specialty education and training of concerned staff should be performed.

A signal-man on shore must instruct a trailer driver properly to adjust the halt position so that an operator of a quay side crane can load container onto trailers smoothly.

2) Improvement of Container Loading/Discharging Operation Control System

When two or more quay side cranes are servicing a vessel, it is necessary to equalize the work loads of each quay side crane. Furthermore, it is important to prepare an operation plan so that the cranes do not interfere with the another. In loading export containers, it is very important to load containers based on the yard planning system by weight, port of discharge, container size and kind of container for stability and safe navigation of vessels.

Refrigerated container and hazardous container must be loaded according to the IMO (International Maritime Organization) regulations.

Required functions for the loading/discharging operation system are as follows:

- Container discharging operation system.
- Container loading operation system.
- Container re-handling operation system.
- Quay side crane allocation system.
- Vessel hull strength calculation system.

Necessary information on containers should be obtained from the shipping lines or it agents as early as possible. Obtaining the information in advance enables a terminal operator to prepare the vessel operation working schedule indicating the order of discharging/loading containers and to minimize the operation time. Before preparing the vessel operation working schedule, it is necessary to obtain the latest stowage bay plan after the last port's operation. The container of necessary information items is as follows:

- Name of vessel and voyage number.
- Date of departing the last port.
- Estimated time of arrival.
- Details of containers=container number, size and weight, port of loading and discharging.
- Special containers=Temperature controlled cargo, IMO classification cargo.

- Draft of vessel at departing the last port and estimated draft at the entry.

In advanced ports, the above information is transmitted with EDI between the terminal operator and the shipping Co, or it agent but in ordinary ports, internet is used.

After loading containers, the operator prepares the stowage bay plan, which indicates the result of the operation, and passes it to a captain or shipping agent. Making the stowage bay plan is an important task of a terminal operator. In advanced container terminals, the shipping agent operation section making stowage bay plan with a computer system. Stowage bay plan includes the following items:

- Prefix and container size.
- Container number.
- Port of loading and discharging.
- Weight and description of special cargo.
- Location in hold/on deck (bay-row-tier).

3) Container Inventory Control System

Inventory control of container yard is the most important task of container terminal. It is essential to grasp the location and kind of containers stacking spot in the container yard to operate a container terminal efficiently.

4) Improvement of Container Receiving and Releasing Documentation System

Regarding the necessary documents to be submitted to the terminal upon receiving and releasing of cargoes, four kings of documents are necessary for exportation while more than ten kinds of documents are necessary for importation. Regarding the documents for importation, there are quite a few documents which require the same data. Thus such documents should be combined and documentation requirement should be simplified.

The simplification of documents would clearly be accomplished in receiving and releasing operation by making optimum use of Customs declaration document which is indispensable for foreign trade cargoes.

In future, the so-called “One Stop Service Window” for operation can be realized by introducing EDI (Electrical Data Exchange).

(2) Container Handling Equipment

1) Quay Side Container Handling Equipment

Choosing Quay Side Container Handling Crane

Each system has its own advantages and disadvantages as briefly mentioned in Table 6.3.3. To select the equipment, the following items should be taken into consideration.

- Quay side Rail Mounted Gantry Crane
- Quay side Mobile Harbour Crane
- Quay side Mobile Truck Crane

Table 6.3.3. Comparison of Quay side Operation system

Kind of Quay side Crane	R.M.G. Crane	M.H. Crane	Truck Crane
Required of Terminal Size	Large	Medium	Very small
Cost Investment (Initial cost)	Large	Medium	Small
Civil Construction Cost	Large	Large	Low
Efficiency of Operation and Productivity	Good	Medium	Low
Flexibility of Operation Work	Medium	High	High
Maintenance Cost	High	Medium	Low
Port Reputation	Good	Medium	Low

Source: JICA Study Team

2) Requirement of Quay Side Gantry Crane (QSGC)

A key factor figuring in the expansion plans of many ports and terminal operators is whether to invest in additional or replacement quay side gantry cranes, necessary to cope with having to service increasingly larger vessels and cargo volume at greater productivity rates.

The rise in orders of quay side crane has closely followed the deployment of larger tonnage without mirroring it exactly. That mean many container terminal operators have been investing in over-sized units in anticipation of serving post-Panamax and super post Panamax vessels. While some ports, notably European and Asian ports, have served bigger vessels than their quay side gantry cranes

They have had to commit to cranes with a bigger outreach to either get major container carriers to call with its biggest vessels or persuade it to stay.

Major container shipping lines have demonstrated that, in some cases, they will wait for bigger quay side gantry cranes to be constructed and commissioned.

More recently, more terminals are seeking to further proof their investment by purchasing quay side gantry cranes that are larger than what is currently required in anticipation of an increase in vessel size. The major concerns with purchasing new quay side gantry cranes needed to work larger vessels are structural size, dimensions and specifications. As speed is central to improving productivity this issue is considered in the Table 6.3.4.

Table 6.3.4. Evolution and Features of Gantry Cranes

Items	Standard Type Panamax	1st Gen, Post-Panamax	2nd Gen, Post Panamax	Super Post Panamax
Innovation Year	1970	1975	1988	1996
Out Reach (m)	Under 35m	36~43m	44~55m	55~65
No of Box Across on deck	Under 13 Row	14 ~ 16 Row	18 ~ 20 Row	Over 23 Row
Hoisting Reach	(+25.0m)~(-12.5m)	(+27.5m)~(-13.0m)	(+36.0m)~(-15.0m)	(+40.0m)~ (-16.0m)
Hosting Speed / minute	72 ~ 36m/min	125~50 m/min	150m ~ 70m/min	180 ~ 90m/min
Travelling Speed /minute	125m/min	180m/min	240m/min	240m/min

Source: JICA Study Team

3) Requirement of Yard Container Handling Equipment

The Introduction of Container Yard Handling Equipment

Currently, main yard equipment are Reach Stackers or Top Lifters. However, these equipment are inefficient in yard utilization. Thus, it would be difficult to cope with the increase in container throughput expected in the near future.

Taking into consideration the current situation, it will be necessary to introduce RTGs

(Rubber Tire Mounted Gantry Crane) around 2012 as yard equipment.

After the introduction of RTGs, it is expected that yard slots would become five (5) times more than at present and, thus, it would become possible until 2022 to cope with the increase in container throughput using the current area of the port (i.e. no expansion of the container stacking area is necessary)

As container handling equipment between the apron and container marshalling yard (C.Y.), the following system is applicable:

The operating machinery which is introduced in Container Terminal and which is generally used must take the following point into consideration.

Choosing Container Yard Handling Equipment

- Rubber Tire Mounted Gantry Crane (RTGs) System
- Rail Mounted Gantry Crane (RMGs) System
- Straddle Carrier System
- Reach Stacker / Top-Lifter System
- On Trailer (Chassis) System

Each system has its own advantages and disadvantages as briefly mentioned in Table 6.3.5. To select the optimum system, the following items should be taken into consideration as essential elements.

Table 6.3.5. Comparison of Container Handling System

Kind of Operation System	RTGs/RMG Crane	Straddle Carrier	Reach Stacker / Top Lift	On Trailer (Chassis)
Required of C.Y. Area	Small	Medium	Rather Large	Huge
Cost Investment	Medium	Medium	Low	High
Balance to Capacity of QSGC	Good	Excellent	Good	Good
Efficiency of Operation	Medium	Medium	Low	High
Flexibility of Operation	Medium	High	Medium	High
Damage Ratio of Container	Low	Medium	High	Very Low
Maintenance Fee /Repair Time	Medium	High	High	Low
Appling of Automation by Computer	Easy	Medium	Medium	Easy
Construction Cost of Pavement	Medium	Heavy	Heavy	Low

Source: JICA Study Team

4) Requirement of Yard Container Movement (Tractor and Trailer)

The Introduction of Yard Container movements handling equipment

The terminal yard tractor head with trailer run between quay side apron and marshalling yard, and transport containers for loading or discharging container vessels. They are also used to speed in terminal yard container movements (e.g. Container inspection, cargo stuffing / un-stuffing of CFS and container repair shop).

(3) Required Container Handling Equipment

1) Required Quay-Side Gantry Crane (QSGC)

The available number of QSGCs for handling containers at the container terminals is a ruling factor in determining the cycle time of container vessels. Hence, it is necessary to provide an optimum number of the container handling equipment to ensure efficient. The required number of QSGCs for handling containers can be estimated using the following formula on some assumptions.

Nqgc = A / (T x η_1 x ρ x Pqgc x η_2 x E)

Where,

Nqgc: Required number of QSGC (units),

A: Annual throughput in 794,000TEUs.

T: Maximum available working hours for the year (8,760 hours)

ρ : Berth occupancy ratio.

(ρ = 0.55% for Pecem Port Container Berth)

Pqgs: Productivity of QSGCs (=27 Boxes / hour/equipment)

η_1: Availability and Peaking Factor (=0.8)

η_2: Container handling efficiency (=0.8)

E: Conversion rate (= 1.72 TEUs / Box)

<u>Calculation of Long Term</u>

Nqgc= (8,760hrs x 0.8 x 55% x 27 x 0.8 x 1.72) = 143,199

= 794,000TEUs / 143,199 = 5.54 6 Units

2) Required Container Yard Handling Equipment

Yard Equipment Requirement

While there is no yard system that can be identified as more appropriate for a particular type of port area, there are some trends that can be identified in the shape of the world's ports.

For some terminals the choice of yard layout and equipment is dictated by container volume and available land space.

The main impact of container carrier strategies on yard equipment requirement is in the container yard area of productivity and service level.

a). Required Yard Equipment

The required number of RTGs in the container marshalling yard is estimated using the following formula on assumption that all containers mounted and un-mounted are to be stacked once temporarily in the container marshalling yard.

Nrtg = Nrtg $_1$ + Nrtg $_2$ + Nrtg $_3$

= 2 x Nqgc + (λ x A) / (T x η_1 x Prtg x η_2 x E) + 2

Where,

Nrtg: Required number of RTGs (Units).

Nrtg 1: Required number of RTGs, mainly for quay-side operation (units).

Nrtg 2: Required number of RTGs, mainly for C.Y operation (units).

Nrtg3: Required number of RTGs stand-by to cope with pre marshalling operation, immobilization due to repairs or periodical maintenance or other unforeseen circumstances (assumed as 2 units).

A: Annual throughput in 794,000TEUs.

T: Maximum available working hours for the year (8,760 hours).

λ : Peaking factor to the daily average handling demands.

λ =(Max Storage Box + Max Gate Activity)/(Min Storage Box + Min Gate Activity).

Prtg: Productivity of RTGs = (18 boxes/hr/unit).

η_1: Percentage of availability = (0.8).

η_2: Container handling efficiency = (0.8).

E: Conversion rate = (1.72/TEU/box).

Calculation of Long Term

- Average Throughput per Box794,000÷1,72 = 461,628 boxes
- Average per day: 461.628 boxes ÷52 weeks ÷7 days = 1,268 boxes
- Maximum handling per day: 1,268 boxes x 1.3 = 1,649 boxes
- Minimum handling per day: 1,268 boxes x 0.7 = 1,015 boxes
- Gate Activity (exclude transhipment box 71 : 29)
- Maximum through gate box: 1,649 boxes x 0.7 = 1,155 boxes
- Minimum through gate box: 1,015 boxes x 0.7 = 711 boxes

λ : (1,649 + 1,155) ÷ (1,015 + 711) = 1.624

Nrtg= 2 x 6units + (1.62 x 794,000) / (8,760x0.8x18 Boxesx0.8 x1.72) + 2

= 12 + 7.41＋2 = 21.41 22 Units

Table 6.3.6. Required Container Handling Equipment

Kind of Equipment	Long Term	Specification
Quay side G. Crane (Existing Harbour Crane)	6Units (2 units)	On Deck 18 Row Stowage Type, Outreach 50m
RTGs (Helping for Existing R.S/T.L)	242Units (4~5 Units)	77'Span 1 over 4 high type RTGs Existing RS / TL

Source: JICA Study Team

3) Required Dimension of Yard Tractor and Trailer.

According to the distance between quay-side gantry crane and marshalling yard, one job cycle time of tractor and trailer shall change. Therefore, an estimation of required number of tractors and trailers for proposed option were carried out on the following conditions.

Travel speed of tractor and trailer:	Average 20 km/hr
Handling cycle time under the gantry crane:	2.0 ~2.5 minute/container
Handling cycle time under the RTGs:	2.5minute/container
Handling productivity of gantry crane (2022):	27 boxes / hour
Container berth length and width (2022):	900 m / 50 m

The number of tractors and trailers required for each proposed option preparing private company (terminal operator) will be estimated as given in Table 6.3.7

Table 6.3.7.Estimated Number of Required Tractors/Trailers

<table>
<tr><th colspan="2">Project Year</th><th>2022</th></tr>
<tr><td colspan="2">For container loading /discharging operation</td><td>20 Units</td></tr>
<tr><td colspan="2">For marshalling yard & CFS repair shop boxes movement</td><td>Tractor x 5 Units
Trailer x 8 Units</td></tr>
<tr><td rowspan="2">Total unit</td><td>Tractor</td><td>25 Units</td></tr>
<tr><td>Trailer</td><td>28 Units</td></tr>
</table>

Source: Calculated by JICA Study Team

As for the yard trailer, the minimum requirement should be equal to the number of prime mover and allowance must be made for additional trailer to serve of container terminal operation for the purpose of special cargo be in temporary storage.

Since it is often necessary to keep container loaded on trailer in the yard, in order to meet operational needs or to speed up the container operation.

The estimated number of trailer for each proposed option given in Table 6.3.7. includes this allowance, which was assumed to be 20%. Not only systematic operation but also management of these tractor/trailer of great importance in the container terminal operation.

Table 6.3.8. Summary of Long Term Project Number of Container Handling Equipment

Project Year	2022	Specification
Quay side Gantry Crane	6 Units	Post Panamax Outreach 50m
Rubber Tier Mounted Crane	21 Units	1 Over 4 High Type
Rail Mounted Gantry Crane	1 Unit	Long Span Type
Auxiliary Existing Equipment		
Mobile harbour Crane	2 Units	MHC 300 Type
Reach Stacker/Top Lifter	7 Units	Various Type

Source: JICA Study Term

6.3.7 Specifications of Container Handling Equipment

(1) Quay Side Gantry Crane

Outreach specifications of quay side gantry crane of Post Panamax Type container vessel are shown as follows. The outline of planned quay side gantry crane is shown in Figure 6.3.5.

- Anti-sway control system.
- Spreader skew adjusting system.
- Job monitoring system.
- Machine condition monitoring system.
- Gale warning system.

Specifications

- Rail span: 30.0m
- Outreach from sea-side rail centre: 50.0m
- Bach reach from land-side rail centre: 16.0m
- Lifting capacity = Total: 60.0m
  - Above rail level: 40.0m
  - Below rail level: 20.0m
- Maximum boom height above rail: 112.5m
- Overall width: 25.6m
- Traversing speed: 240.0m/min
- Boom hoisting cycle time: 8 min/cycle
- Hoisting capacity: Single lift: 40.0 tons
- Twin lift: 60.0 tons
- Without spreader: 70.0 tons
- Spreader type (telescopic type): 20'/40' and 45'
- Power supply by electricity: AC6,000V, 50Hz,3 Phase

(2) Rubber Tire Mounted Gantry Crane (RTGs)

The RTGs are planned to have the space of 4 stack 1 over pass, 6 row plus 1 trailer traffic lane 8see Fig,. 6.3.6).

- Auto steering system.
- Anti-sway control system.
- Spreader skew adjusting device.
- 90 ° degree steering for changing travelling lane.
- Job monitoring system.

Specification:

- Rated load (under spreader): 40.0 tons
- Type of spreader (telescopic type): 20'/40' and 45'
- Wheel span (internal) : 23.5m
- Lifting capacity: -lowest: GL + 0m
- -highest: GL + 15.2,
- Wheel base: Min 6.4m
- Overall width: Max 12.2,
- Number of gantry wheels: 2 tiers/corner (total 8 wheels)
- Power supply: Diesel engine electric power generator on the self

(3) Tractor Head and Trailer

The Tractor head and trailer is planned to have the space of high-way tractor and trailer 20'/40' box combined type and heavy duty structure.

Specification:

- Engine House-power: Approximately 270~300 Hp
- Trailer (20'/40'and 45' both type): with heavy duty flipper guide

(4) Rail Mounted Gantry Crane (RMGs)

Refer to Figure 6.3.3. for the details of railway operation area arrangement, and required number of equipment:

Specification:

- Long Span Rail mounted gantry crane: 1 Unit
- Rail span: 18.0m
- Out Reach: 9.0m
- Hoisting height 8.0 meters
- Hoisting capacity: 40.0 tons
- Power source: Electricity high voltage

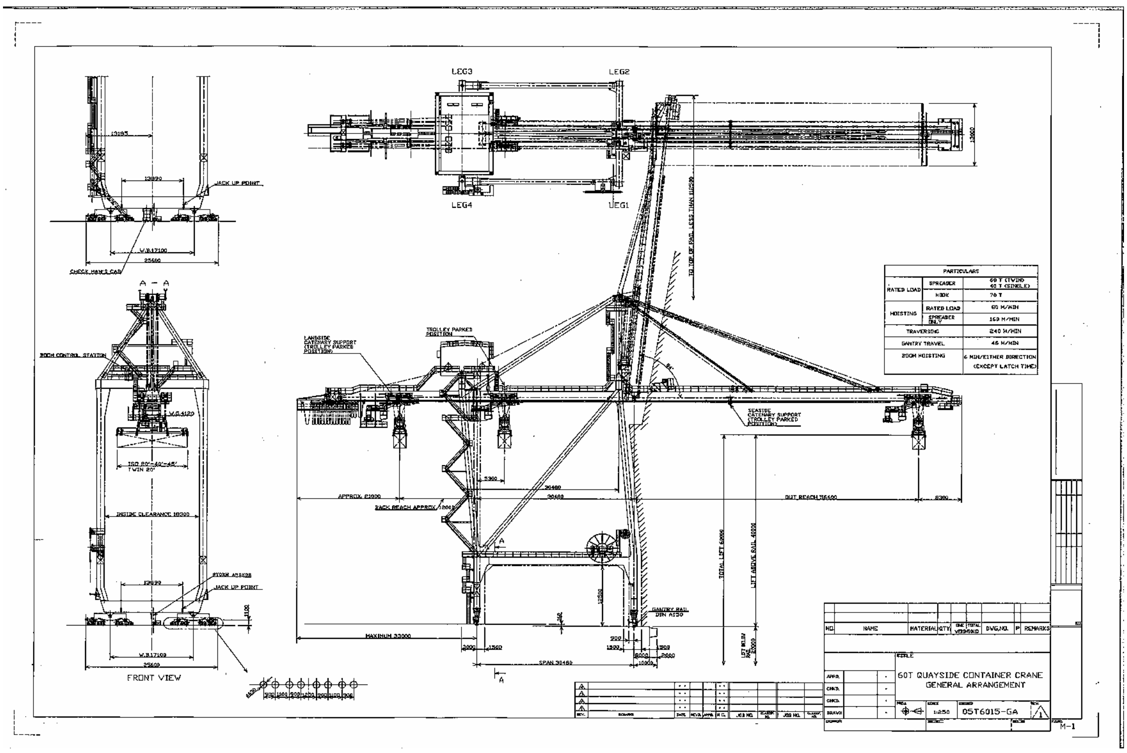


Figure 6.3.5. Profile of Quay side Gantry Crane

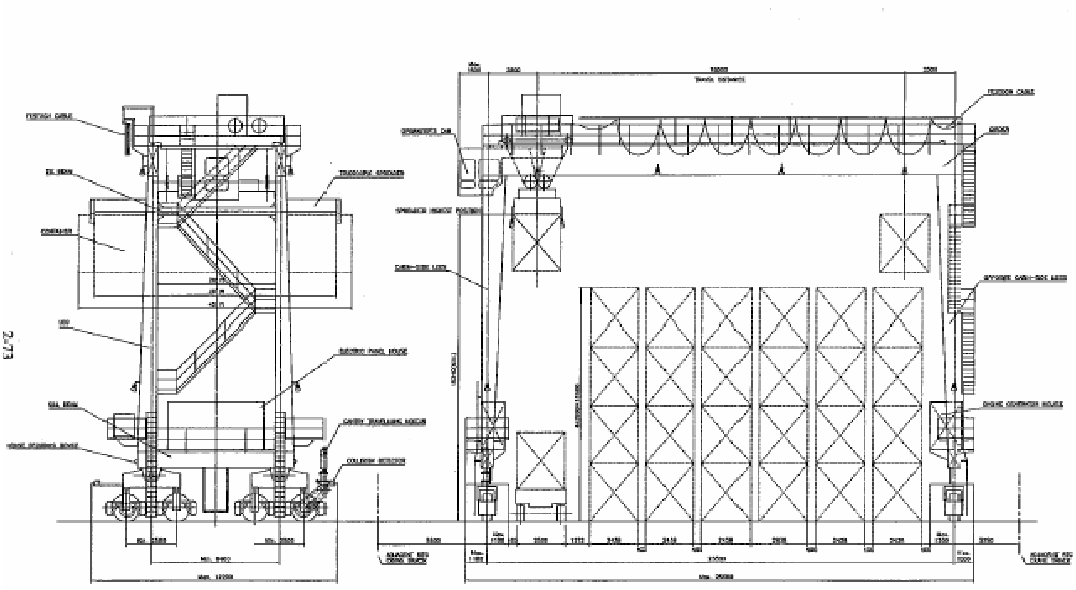


Figure 6.3.6 Profile of Rubber Mounted Gantry Crane

6.3.8 Conventional Bulk Cargo Operation System

Conventional vessel operation efficiency varies significantly depending on the skilled labour and proper cargo handling tools introduced. For improvement of conventional cargo and warehouse operation

1) Improvement of efficiency of transfer among quay side apron and container (cargo) storage area.

Expansion of cargo handling equipment e.g. Fork lift trucks and within the warehouses cargo handling tool.

2) Quick dispatched for calling vessels.

-Establishment of swift information acquisition system of calling vessels.

-Introduction of berthing schedule system taking into account the cargo handling efficiency.

3) Prevention of cargo contamination by setting up partition for clean cargo and dust cargo (e.g. cotton / paper goods and dirty cargo) in the warehouse.

(1) Dry Bulk Cargo Handling Operation System

Main bulk cargoes which are expected to be handled in the near future are soybeans and uranium mineral for outbound operations, and iron ore and fertilizer for inbound operations, respectively. Equipment which is installed on the quay side as well as belt conveyer system are used to handle such cargoes.

The equipment installed on the quay side serves both for loading and unloading purposes by exchanging the peak portion. In the case of loading, peak portion should be exchanged to universal peak pipe. In the case of unloading, it should be exchanged to vertical bucket chain.

As the equipment on the quay side can serve both for loading and unloading operations by reversal method, the reduction in capital investment can be expected.

The quay side and the storage site are connected via belt conveyers. The belt conveyers, depending on operation modes, can reverse rotation. Attention should be paid to combination parts of the belt conveyers.

Outbound operation of dry bulk cargo is conducted through automated connection with silos.

Regarding inbound operation, by connecting with the storage site, the combined method of stacker/re-claimer, aiming at the efficient operation and cost reduction, makes it possible the method where stockpiling and re-claimer function are combined.

Recommended belt conveyer specifications are mentioned in Table 6.3.9.

Table 6.3.9 Specification of Belt Conveyer

Function Item	Specification
Maximum Capacity	2,500 tons / hour
Belt Width	1,600mm
Travelling speed	230m/min ~ 280m/min
Load factor per meter	600kgs / meter

Source: JICA Study Team

1) Un-loader/loader and Stacker/Re-claimer for Bulk Cargo Handling Equipment.

With regard to handling equipment for bulk cargoes, such equipment was previously developed and used exclusively as per the type of cargoes.

However, recently, as the types of cargoes handled diversified, multi-purpose type of such equipment which can handle various type cargoes are frequently used.

Since this equipment is a order-made equipment where the requests of the purchasing body are accepted, there is no standard specification.

Specification of such equipment various widely are among the ports introducing such equipment.

As for purchasing body, it is essential to propose a plan to manufacturer by reviewing in advance fully the important points from the structural point of view, and to introduce the most suitable equipment for the handling cargoes.

The points to review in advance are as follows;

- Efficiency per hour (Productivity).
- The characteristics of the place where such equipment is to be installed.
- Quality of maintenance method.
- Annual running cost.
- Allocation and sharing system among each machine and function.
- Environmental consideration regarding surrounding area.

(2) Liquid Bulk Cargo Operation System

Current operation system applied to liquid bulk cargoes is only transhipment from mother vessel to feeder vessel. If the storage tank facilities are installed upland, pipe-line transportation system can be applied. However, it should be noted that the efficiency of the operation largely depends on the performance of pumps and maintenance of pipes.

It is windy and there are large swell and wave in and around Pecem Port. In order to protect marine pollution, it is necessary to expand the oil fence and adopt an automated spreading system

6.4 Connection to the Inland Transport Network

Land transport network composed of railway and road linked to a port is a determinig factor of a port hinterland as well as the location of principal neighbouring ports and their capacities, and the distribution of exporters and importers and aspects of their economic activities. Hence, prior to making the Long-Term Development Plan of Pecem Port, the future inland transport network was envisaged based on the information obtained from the authorities concerned including the railway companies.

When making the Long-Term Port Development Plan, it was assumed that the following railway project to construct new lines or improve the existing lines to be connected to Pecem Port will be completed before the target year of 2022 of this study.

- Route: Eliseu Martins — Salgueiro - Missao Velha - Pecem Port (New line construction from Eliseu Martins to Missao Velha and Improvement from a narrow gauge (1m) to a broad gauge (1.6m) from Missao Velha to Pecem Port of approximately 1,040 km long in a total)

After the completion of the new land transport network with the broad gauge railway lines, Pecem Port is expected to function as a gateway of the northeast region and beyond to the overseas trade partners so as to contribute to regional devellopment of Ceara State, the northeast region and beyond..

In addition to the current exports through Pecem Port such as fresh fruits, cashew nuts, shrimps, and textile related products generated mainly from Ceara and its border states, agricultural products harvested in Cerrado (wooded plateau) are considered to be the prominent potential cargoes to be exported through Pecem Port. Cement and/or clinker are also considered to be a potential cargo via Pecem Port. The possibility of shipment of Cerrado products is mentioned in the next section.

To receive the above-mentioned new cargoes from the expanded hinterland of the Port expected to be brought in mainly by railways, Pecem Port is required to prepare railway car receiving facilities with well-designed layout and sufficient capacity of tracks. From this viewpoint, track layout plan has been made (see Figs. 6.3.1 – 6.3.4).

6.5 Hydrological and Coastal Study

6.5.1 Incidents Involving Moored Vessels in Present Port

(1) Investigation of Incidents Involving Moored Vessels

There have been incidents at pier No.1 involving moored vessels concerning ship motion since the port opened. According to interviews with individuals involved, incidents of breaking mooring lines and of damage to mooring posts have taken place. The main reason for these incidents is swell waves. Table 6.5.1 shows the incidents involving moored vessels due to swell waves from June 2004 to May 2005. Though the frequency of incidents during the rainy season is much higher than that during the dry season, these incidents occurred throughout the year.

Table 6.5.1 Incidents Involving Moored Vessels at Pier No.1 due to Swell Waves (Since June 2004 to May 2005)

Mooring		Ship Name	Mooring Position	DWT	Wave Condition			Incident
Date	Time				Hs(m)	Tp(s)	Direction	
7/26/2004	6:40	OSTFRIESLAND	P1 Ext - BE	17,800	-	-	-	Serius incidents, ropes breaking, ship in collision route towards the bridge, berth change.
10/26/2004	16:45	CALA PARADISO	P1 Int - BB	30,250	-	-	-	During the stay in the Port, 04 dock lines breaked.
10/11/2004	7:45	CALAPARANA 2	P1 Ext - BE	26,100	-	-	-	High instability of the ship, continuous support of 02 tugboats on portside, with pilot on board, without breaks on the anchorage.
1/18/2005	17:18	CALA PARADISO	P1 Ext - BE	30,250	-	-	-	Bow anchorage, 02 broken ropes, 01 normal, the other with steel rope. Very unstable ship.
1/22/2005	12:45	MSC GIORGIA	P1 Int - BE	29,693	-	-	-	Strong ship oscillation, there was some rope breaking.
4/2/2005	9:55	MAERSK FUNCHAL	P1 Ext - BE	11,150	1.54	7.7	54	In 02/03 there was mooring attempt, however it was aborted.
8/2/2005	10:20	MARINUS GREEM	P1 Int - BE	?	1.49	10.0	38	During the unload operation, there was some rope breaking.
10/2/2005	15:45	CAP SAN LORENZO	P1 Ext - BB	50,200	1.34	9.1	39	During mooring maneuver, the dock line to Eridanos tugboat breaked.
8/3/2005	9:25	MAERSK FALMOUTH	P1 Ext - BE	11,150	-	-	-	Very dangerous unmooring, ship near Pier I, there was collision with the structure of head 07 in external berth.
3/20/2005	8:15	LAURA MAERSK	P1 Ext - BE	63,200	1.31	13.3	34	There was rope breaking during unmooring.
3/21/2005	14:40	MSC GIOVANNA	P1 Ext - BE	29,693	1.24	13.3	35	There was breaking of dock lines during operation.
3/22/2005	0:01	MAERSK FUNCHAL	P1 Ext - BE	11,150	1.14	14.3	35	During operation, there was a ship collision with Pier I, head 08, the end of operation and unmooring was anticipated .
3/23/2005	13:35	LIBRA SALVADOR	P1 Ext - BE	33,742	1.08	11.8	19	Pier I structure damaged, ship collision with head 08.
5/23/2005	10:52	JUNIOR S	P1 Int - BE	?	-	-	-	Mooring with high level of dificulties, presence of Swell, gusts = 17m/s, waves 2,5m, low visibility, torrential rain.

Remark
P1 Pier No.1
Ext external (offshore side) Berth
Int. Internal (Onshore side) Berth
BE Starbord Side
BB Port Side

Figure 6.5.1 shows the wave spectrums and mean wave direction for each frequency for one of these incidents that happened March 22nd, 2005. In this incident, the vessel of 11,000 DWT was moored at the offshore side of pier No. 1. From the video picture, it was observed that rolling and pitching were predominant in the ship motion. During this incident, the wave height was somewhat smaller (H_s=1.1m) than normal in Pecém. However, the peak frequency of wave spectrums was 0.07 Hz (T_p=14.3s) and mean wave direction at peak frequency was 35 degrees (NE). From the video picture, the oscillation period of rolling for this vessel was observed to be of about 14 to 16 s. This period nearly harmonized with the natural period of rolling for the same size of vessel with predicted cargo condition. Therefore, this incident is presumably due to the fact that the peak frequency of wave spectrum was harmonized with the natural period of rolling for the vessel.

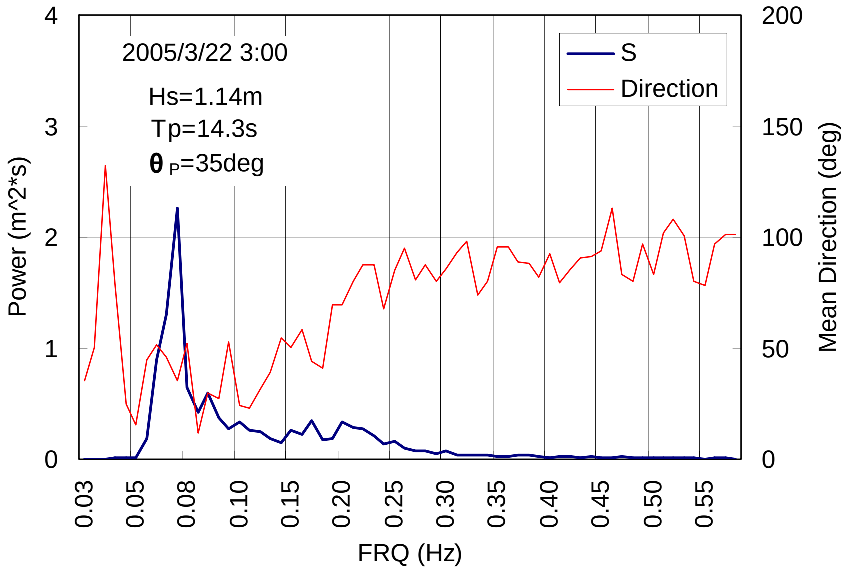


Figure 6.5.1 Observed Wave Spectrums and Mean Wave Direction (March 22nd, 2005)

(2) Possibility of Causing Ship Motion Problems

There are two kinds of long period waves which affect the ship motion problem. They are, swell waves and long period waves (called "surf beat"). The six kinds of ship motions are pitching, rolling, yawing, surging, swaying and heaving. Generally, sway, rolling and pitching are caused by the swell waves because the natural period for these motions is nearly identical to the wave period for swell waves at about 8 to 30 seconds. On the other hand, the surf beat with a period of more than 30 to 300 seconds affects the surge motion. In the case of Pecém Port, the swell waves are the main cause for ship motion. To confirm this, the rolling motion produced by swell waves has been examined. The natural period of rolling (T_{roll}) is calculated by using the following formula.

$$T_{roll} = 2.01 * K_{xx} / \sqrt{GM}$$

Here,

K_{xx} : Radius of Gyration (= 0.3 to 0.4*B, B: Width of vessel (m))

GM : Distance from the Metacenter to the Center of Gravity (m)

Table 6.5.2 shows the calculated natural period of roll for each size of container vessel which arrives in Pecém port. The value of GM changes for each cargo condition. In this study, the value of GM was calculated with the assumption that the GM under full cargo is 0.04*B and that arriving container vessels have 70 % of full cargo. The calculated natural period of rolling changes from 13s to 20s according to vessel size. There is a possibility of ship motion problems when the magnitude of wave frequency spectrums with almost the same period as the natural period for the ship becomes high. Figure 6.5.2 shows the frequency and cumulated distributions for the wave period corresponding to the peak of frequency wave spectrums (T_p). About 10% of waves observed throughout the year have a period exceeding 13 second. The possibility of ship motion problems in Pecém at any point in time is equal to or greater than the frequency distribution of waves with periods similar to those of the ship.

Further, as shown in Chapter 3, the frequency wave spectrums in Pecém usually have two peaks corresponding to the components of swell and sea waves. When the energy of the sea waves exceeds that of the swell waves and the first peak of the spectrums appears at the corresponding frequency of the component of the sea waves, the representative value for wave period (T_p) becomes short. However, the component of swell waves also exists even though the representative value for wave period is short, there is a possibility for it cause the same problems.

In order to improve the present condition for moored vessels, it is necessary to expand the west breakwater. The required expansion length of the breakwater is presented in Section 6.5.2 of Chapter 6 and 9.5.2 of Chapter 9.

Table 6.5.2 Calculated Natural Period for Rolling

DWT	B (m)	K_{xx} (m)	GM (m)			Natural Period for Rolling (s)		
			Full	Full*0.7	Light	Full	Full*0.7	Light
10,000	21	7.4	0.84	1.19	2.00	16.1	13.6	10.4
20,000	25	8.8	1.00	1.30	2.00	17.6	15.4	12.4
30,000	29	10.2	1.16	1.53	2.39	18.9	16.5	13.2
40,000	32	11.2	1.28	1.60	2.34	19.9	17.8	14.7
50,000	34	11.9	1.36	1.65	2.33	20.5	18.6	15.7
60,000	37	13.0	1.48	1.74	2.33	21.4	19.8	17.1

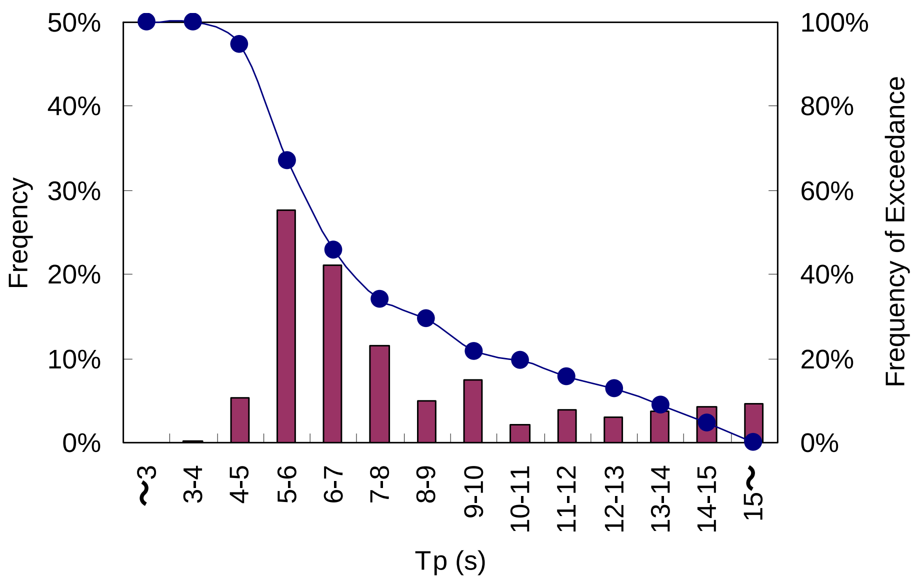


Figure 6.5.2 Frequency and Cumulated Distributions for Wave Period (T_p)

6.5.2 Estimation of Calmness

The layout of offshore breakwaters for the long-term port development plan should be determined in such a way as to maintain the required calmness inside the basin. To estimate the distributions of wave heights inside the basin, which is necessary to estimate the calmness, a numerical computation for the wave field has been conducted. To estimate the wave height inside the basin with high accuracy, the wave diffraction, refraction and reflection should be considered under the expected conditions of the wave field with directional wave spectrums. Some numerical models have been proposed, however, currently, the models that can consider the above-mentioned conditions are very limited.

One of the causes of the error in estimation of calmness at existing pier No.1 was the failure to consider the directional wave spectrums in the physical model test. In this study, the newly developed numerical computation model, “Time-Dependent Mild Slope Equation on Multi-Directional Irregular Waves” (Ishii and Isobe, 1994[1)]), has been applied to allow the estimation of the calmness with consideration for almost all the conditions of the actual wave field. The input conditions used on this computation are shown in Table 6.5.3. Here, S_{max} is a parameter that represents the degree of directional spreading of Wave Energy. According to the Port Design Standard in Japan (1999), S_{max} is set as 10 for wind waves and 25 for swell. Since considering wave breaking is not necessary for the estimation of calmness inside the basin, it has been eliminated in this computation.

Table 6.5.3 Input Conditions for the Computation of Wave Field

Wave Direction	T1/3(s)	Smax	Water Level	Remark
NNE	10	30	MSL	Swell Wave
NE	10	30	MSL	Swell Wave
ENE	8	20	MSL	Sea Wave
ESE	7	10	MSL	Sea Wave

In order to obtain the frequency distribution for wave height and direction, which is necessary for the prediction of calmness, the newly processed frequency distribution with existing daily data from 1997 to 2000 was adopted (refer to the Chapter 3). In the Technical Standards and commentaries of Port and Harbour Facilities in Japan (1999), it is specified that the appearance frequency of wave height not exceeding 0.5m shall be achieved for 97.5% or more of the days of the year for medium and large sized vessels. Actually, the threshold wave height for cargo handling should be determined considering the wave conditions, type, size of vessel and cargo handling characteristics. Container vessels generally require a high degree of calmness compared with general cargo vessels. Furthermore, it has been pointed out that the calmness of the outer port, which is located in the offshore region, becomes lower due to long period waves (swell waves). To deal with the conditions mentioned above, it is necessary to determine the threshold wave height in consideration of the acceptable amplitudes of ship motion. The threshold wave height for each type of ship has been presented in a newly issued Japanese design manual for long period waves including swell waves (2004). Table 6.5.4 shows the threshold wave height for container cargo handling. As the wave period becomes longer and the wave direction to the ship becomes larger, the threshold wave height becomes considerably lower than 0.5m.

The most frequent wave period along the shore of Pecém port is 5 to 6 seconds; however, about 20% frequency distributions of wave periods of more than 10 seconds exist throughout the year. In consideration of this wave condition together with the location of Pecém port's outer region and cargo handling for containers, the threshold wave height is expected to be less than 0.5m. Hence, the calmness for the proposed container berth and for the existing pier No.1 has been estimated by using threshold wave heights of both 0.5m and 0.3m. The calmness for other berths has been estimated by using the threshold wave height of 0.5m.

The location map for calmness estimation points is shown in Figure 6.5.3.

Table 6.5.4 Threshold Wave Height for Container Cargo Handling (Unit: m)

Ship Size (DWT)	Wave Direction (deg)	Wave Period (s)					
		4	6	8	10	12	15
20,000 DWT	15	0.50	0.50	0.50	0.50	0.50	0.45
	30	0.50	0.50	0.50	0.50	0.50	0.40
	45	0.50	0.50	0.50	0.50	0.30	0.20
	60	0.50	0.50	0.50	0.25	0.20	0.20
30,000 DWT	15	0.50	0.50	0.50	0.50	0.50	0.50
	30	0.50	0.50	0.50	0.50	0.50	0.45
	45	0.50	0.50	0.50	0.50	0.45	0.20
	60	0.50	0.50	0.50	0.40	0.20	0.20
40,000 DWT	15	0.50	0.50	0.50	0.50	0.50	0.50
	30	0.50	0.50	0.50	0.50	0.50	0.50
	45	0.50	0.50	0.50	0.50	0.50	0.20
	60	0.50	0.50	0.50	0.50	0.25	0.20
50,000 DWT	15	0.50	0.50	0.50	0.50	0.50	0.50
	30	0.50	0.50	0.50	0.50	0.50	0.50
	45	0.50	0.50	0.50	0.50	0.50	0.25
	60	0.00	0.50	0.50	0.50	0.25	0.20

(Source: Assessment Manual for Long Period Waves in Port Basin, 2004)

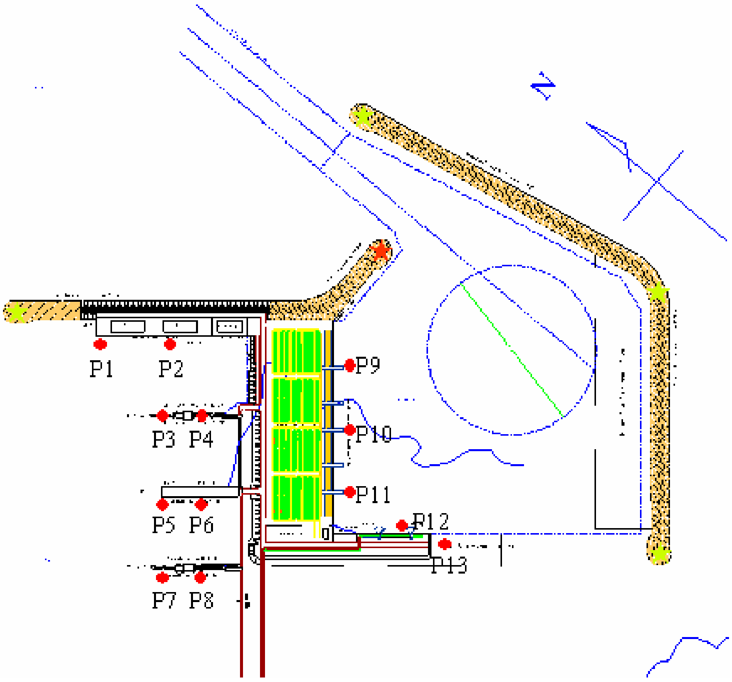


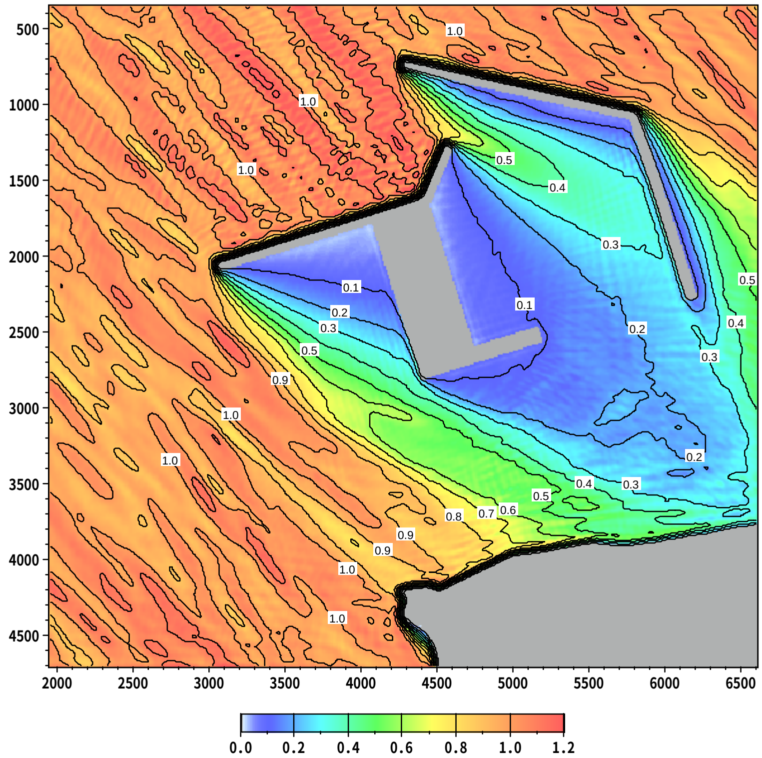
Figure 6.5.3 Calmness Estimation Points

Figure 6.5.4 and 6.5.5 show the numerical computation results for wave fields for each incident wave direction. The shadow region for waves is changed corresponding to the difference of incident wave direction. The wave tranquillity at the side of the existing basin becomes worse when the swell waves are propagated from NNE to NE direction. On the other hand, a high degree of wave tranquillity can be secured for all incident wave directions at the side of the new basin.

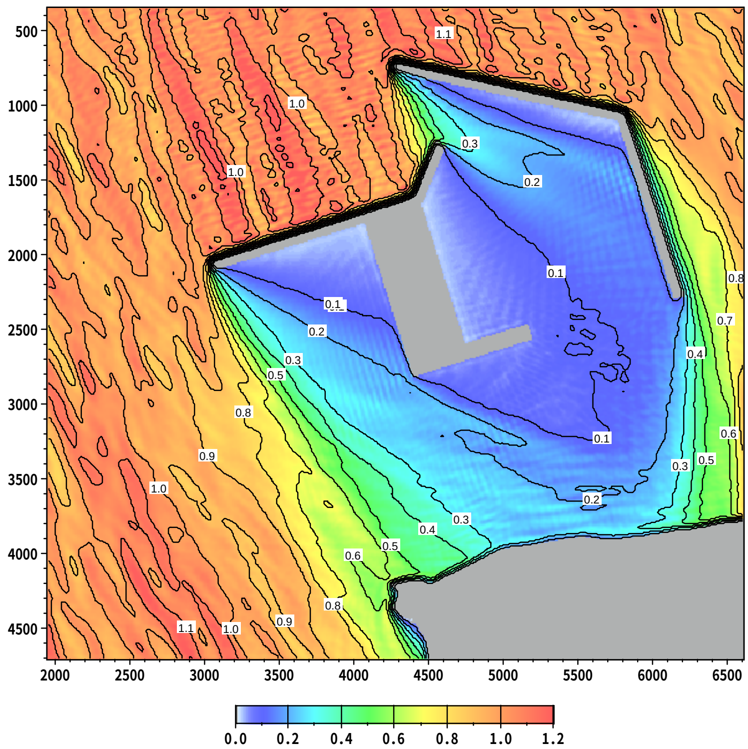
Table 6.5.5 shows the obtained calmness at each berth point.

- The proposed new container and grain berth can be protected from both swell and sea waves due to construction of Main and Sub Breakwaters, and 100% calmness can be secured even for the case of the threshold wave height of 0.3m.
- The extension of the West Breakwater is necessary to secure the required calmness at existing pier No.1. The calmness at the head position of pier No.1 can be improved from 89.3% to 95.7% at the head position (Point No.4) by a 300m extension in the length of West Breakwater. The Pier No.3 (multi-purpose and fruits berth) also can secure 100% calmness.

The calmness at the Pier No.0 is also shown in Table 6.5.5 for reference, even though this facility is not included in this study. Assuming H_{cr} =50cm as the threshold wave height at Pier No.0 the same as Pier No.2, the obtained calmness is 89.2% and 91.3% at the head and center position, respectively. This calmness is worse than that for the Pier No.1 in the present condition. If the calmness with higher value is required, the further extension of the West Breakwater is necessary to prevent the intrusion of swell waves. This study is presented in Apendix A.6.5.2.

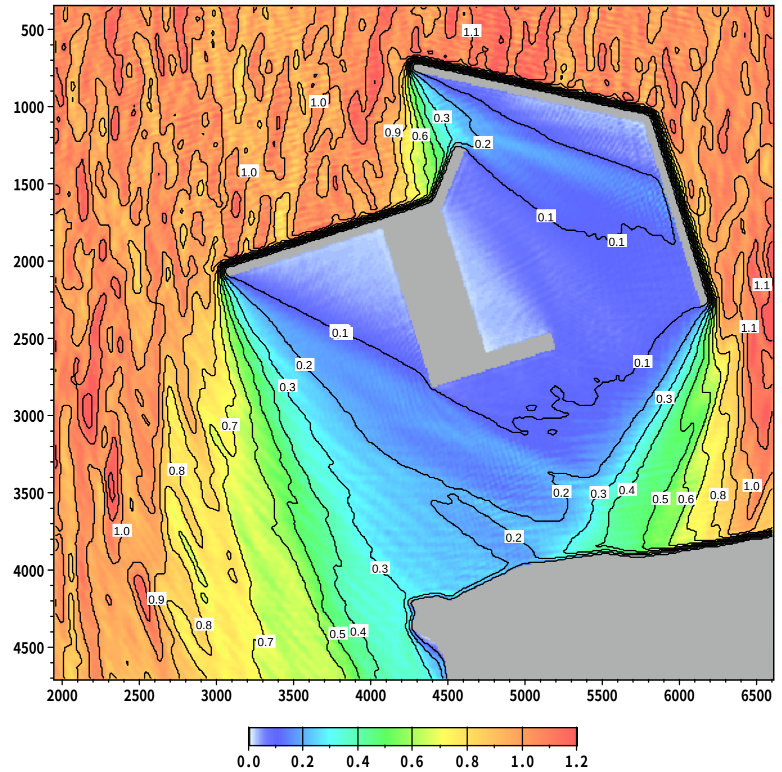


(1) Wave Direction NNE (T=10sec, Smax30)

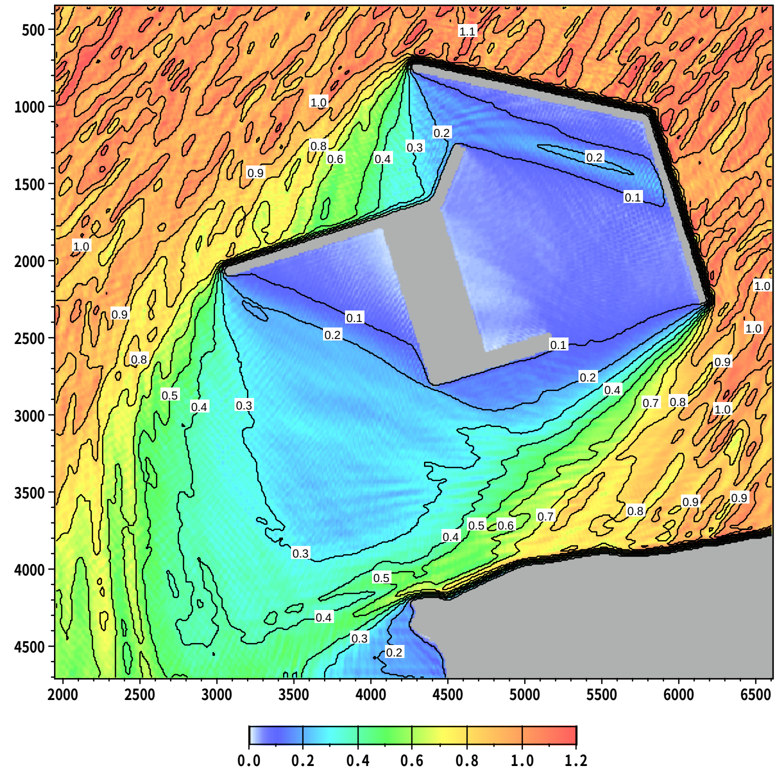


(2) Wave Direction NE (T=10sec, Smax30)

Figure 6.5.4 Distribution of Wave Height Rate (H/ Hi)



(3) Wave Direction ENE (T=8sec, Smax20)



(4) Wave Direction ESE (T=7sec, Smax10)

Figure 6.5.5 Distribution of Wave Height Rate (H/ Hi)

Table 6.5.5 Estimated Calmness at Each Berth

Berth	Position	Point No.	Long-Term Plan		Present	
			Hcr<50cm	Hcr<30cm	Hcr<50cm	Hcr<30cm
Pier No.3	Head	1	-	100	-	100
	Center	2	-	100	-	100
Pier No.2	Head	3	100	-	93.0	-
	Center	4	100	-	100	-
Pier No.1	Head	5	95.7	70.3	89.3	29.1
	Center	6	99.2	91.9	93.0	64.0
Pier No.0 (for Reference)	Head	7	89.2	-	-	-
	Center	8	91.3	-	-	-
Container Berth	Head	9	100	100	-	-
	Center	10	100	100	-	-
	Bottom	11	100	100	-	-
Grain Berth	Head	12	100	-	-	-

6.5.3 Coastal Impact Study

The present port layout with a detached offshore berth was chosen to avoid disturbing the westward littoral drift around this coastal area. The prediction of the impact on the surrounding coast is one of the most important studies in the environmental impact assessment for the future development plan.

INPH and DHI (1997) have carried out a coastal impact study for the existing port and for the temporary jetty, which was constructed during the implementation period.

At Pecém port, a shoreline monitoring survey 4km long has been continuously carried out and aerial and satellite photographs have also been taken since before construction of the port. These data are available to determine the actual coastal change after construction.

In this study, the impact on the surrounding coast from the long-term development plan has been predicted using a numerical computation method with the monitoring survey data and aerial and satellite photographs as supporting data.

(1) Characteristics of Littoral Drift

In the Pecém area, it is obvious that the westward littoral drift is dominant. From the geographical shape of coastline shown in satellite photograph (Photo. 6.5.1), some rocky headlands exist in the area from Fortaleza to Pecém. The main rocky headlands around this coast are “Ponta do Mucuripe” and “Ponta do Pecém”.

The west side of the coast across the headland is curved and the east side runs in an almost straight line. This shape of shoreline was formed by the rocky headland intercepting the westward littoral drift.

Photo 6.5.1 Geographical shape around Pecém Coast

From the previous studies, the net annual littoral transport at Mucuripe port was estimated at about 600,000 m3/year (VALENTINI, 1997) to 876,000 m3/year (INPH, 1992). On the other hand, the net annual littoral transport at Pecém area was estimated to be in the order of 350,000 m3/year (INPH & DHI, 1997).

The westward littoral drift is caused by both swell and sea waves. The sea waves, approach the coast at an oblique angle causing strong westward littoral drift on the eastern side of Ponta do Pecém. Along the western side of the headland, the littoral drift is greatly reduced due to the sheltering effect of Ponta do Pecém. The reduction of littoral drift and the change of orientation of coastline on the west side of the headland cause the sediment accumulation at the west side of headland. During periods of sea wave dominance, a sand spit develops on the lee side of the headland. The swell waves cause sediment transport, which is directed towards the east on the eastern side of Ponta do Pecém and towards the west on the western side. This transport pattern counteracts the accumulation of sediment around the headland. The net sediment transport at the east side reduces due to the action of swell waves. At the west side of Ponta do Pecém, the swell waves give rise to additional westward sediment transport.

The pattern of littoral drift for sea and swell waves is shown in Figure 6.5.6.

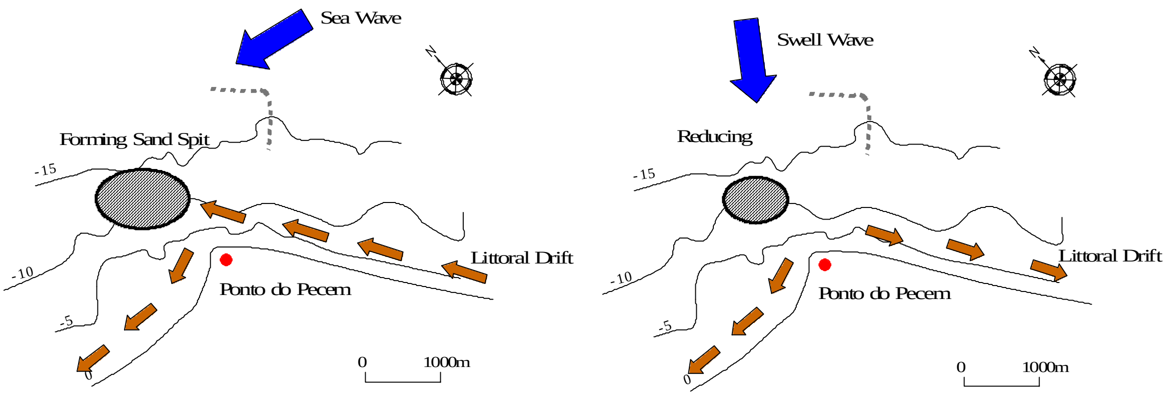


Figure 6.5.6 Pattern of Littoral Drift for Swell and Sea Waves

(2) Process of Shoreline Change

1) Before Construction of the Port

In the previous coastal impact study, which was conducted by INPH & DHI (1997), the retreat of the coastline in front of Pecém village was observed from the aerial photographs to be approximately 50 m during the 25 years before construction of

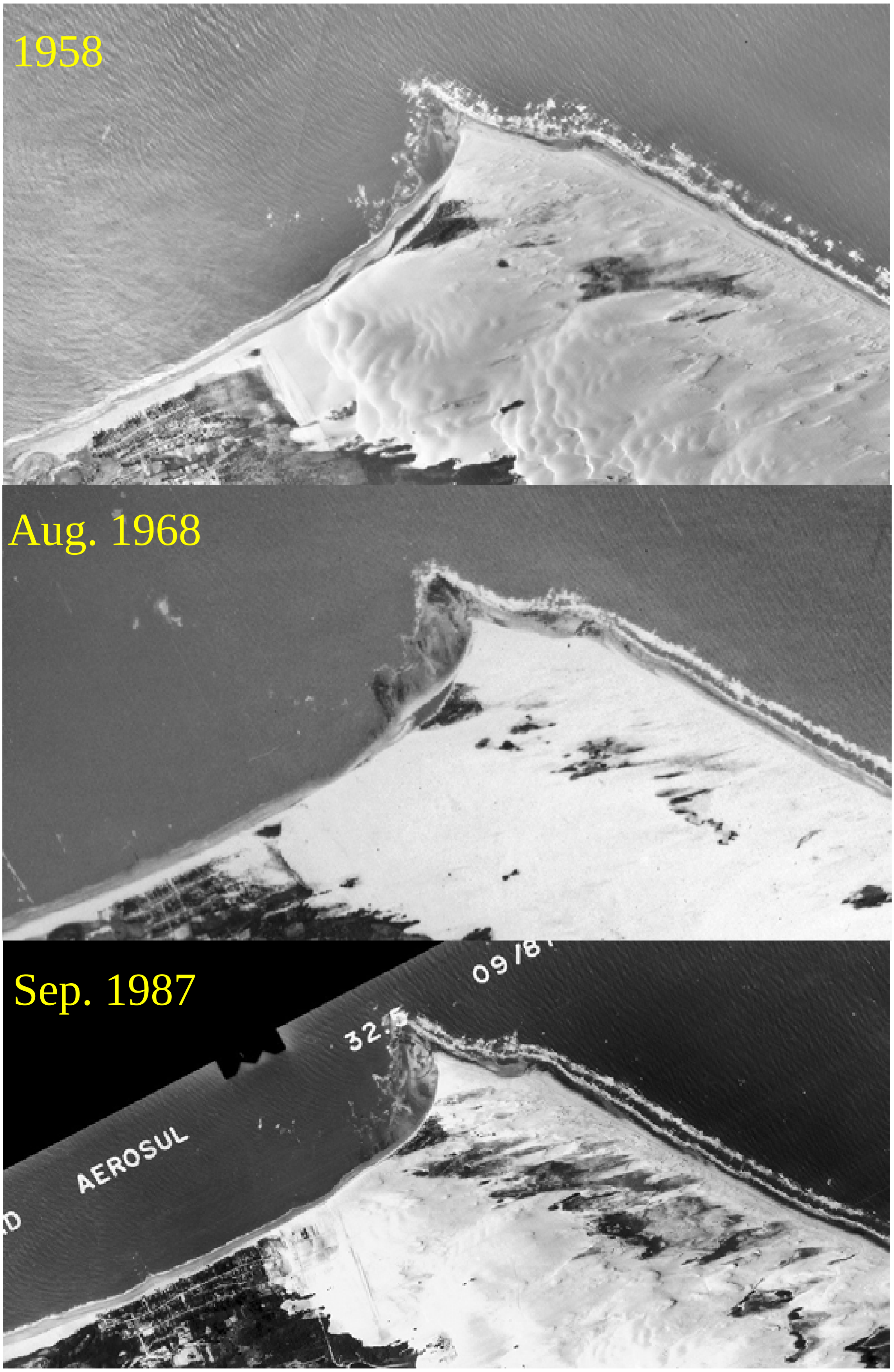


Photo 6.5.2 Shoreline around Pecém Port in 1958, 1968 and 1987

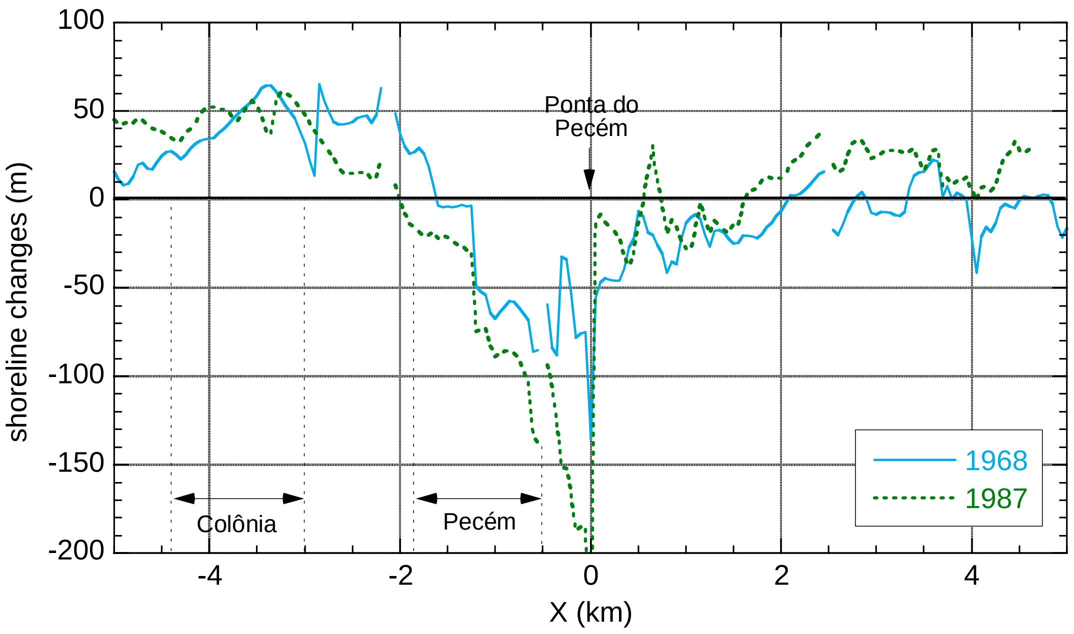


Figure 6.5.7 Shoreline Change (Reference Year 1958)

Pecém Port. The JICA Study Team has conducted image processing of vertical aerial photographs and satellite images to examine the coastal change since the past to the present.

Photo.6.5.2 shows the processed aerial photographs around Pecém Port in1958, 1968 and 1987 with the same area and scale, and Figure 6.5.7 shows the shoreline change for a distance of about 20km around the Pecém coastal area that has been traced from the processed aerial photographs. Here, the shoreline in 1958 was used as the base line data. This result has some degree of error because of the lack of information about tide conditions, however, it was observed that the coast line from Ponta do Pecém to Pecém village has obviously retreated since 1958 by about 60m during the subsequent 30 years (about 2m/year). Especially, remarkable retreat has occured between 1968 and 1987. From Photo 6.5.2, it was observed that the vegetated area (black part in the photograph) behind the coastal dune was expanding during this period. The yearly rainfall from 1984 to 1986 was more than 2,000mm/year, much higher than average. This might have caused the change in the dunes. The sand transported from the dunes is one of the main source of sand supply at Pecém coast. From this, the change in the condition of the dunes is a possible cause of the retreat of the Pecém coast. At the east side from Ponta do Pecém, no remarkable difference during the period of 1958 to 1996 was observed.

2) During and After the Construction Period

The shoreline around Pecém Port during and after construction of the existing port is shown in Photo.6.5.3. Here, a Satellite photograph taken in 2005 was newly obtained by the JICA Study Team. During the construction period, the construction of the temporary jetty (TEP) was completed in March, 1997, and the removal was done in the first part of 2001. The offshore breakwater was constructed over about 3 years from the beginning of 1999 until December of 2001. From the difference between the photographs taken in December 1997 and in March 2001, it is obvious that the shoreline on the east side from TEP accumulated and the shoreline in front of Pecém village retreated. After removal of TEP, the deposited sand at the east side of TEP moved to the west side and formed the sand spit on the west side of Ponta do Pecém as shown in the photograph of December 2001 (Photo.6.5.4). This sand spit was expanding to the westward, and the coastline in front of Pecém village recovered to almost the same as the previous condition.

Figure 6.5.8 shows the comparison of shoreline change, which was obtained from the monitoring survey from 1996 until 2004. In this figure, the shoreline obtained in 1996, which shows the condition before construction, was taken as the reference. After construction of TEP, the westward littoral drift was completely blocked and this caused shoreline accumulation east of Ponta do Pecém and caused retreat on the west side. The change to the shoreline was caused mostly within 1 or 2 years after construction of TEP. The shoreline on the east side (up-drift side) of TEP accumulated about 180 m in maximum after construction of TEP. The net annual littoral transport can be estimated by measuring the size of accumulation area together with the active depth for sediment movement (d_{act}). The size of the accumulation area can be measured as about 78,000m2 over 2 years from the aerial photograph analysis and 40,000 m2 for 1 year from the monitoring survey results. The active depth for sediment movement d_{act} is estimated at about 7 to 9m considering the wave condition of Pecém and other examples, thus, the annual littoral transport Q (m^3/year) can be roughly estimated as about 280,000 to 360,000 m^3/year. This volume is of the same as that in the previous study (INPH &DHI, 1997).

At the east side (down-drift side) of TEP, the maximum of about 200 m of shoreline retreat occurred on the lee side of TEP, and about 30 to 40 m in front of Pecém village. Photo 6.5.5 show pictures taken in February of 2001 and August of 2005 from almost the same position at the beachfront near Pecém church. The berm height was about 1.5 to 2.0m lower in 2001 than in 2005. The foreshore slope is about 1/20 from the cross-section of the monitoring survey, and the same width of retreat of 30 to 40 m can be obtained from Photo 6.5.5.

Figure 6.5.9 shows the shoreline change both in August 2004 and in November 2005. Here, the shoreline in 1987 is used as baseline data. If the movement of sand deposition at Ponta do Pecém is still continuing, the shoreline should retreat on the east side and accumulate on the west side. However, no remarkable change of shoreline was observed between 2004 and 2005. From this, it is expected that the drastic changes caused by the construction and removal of TEP, have almost finished. The coastal impact due to the existing port will be tracked from now on by conducting shoreline monitoring.

Photo 6.5.3 Shoreline around Pecém Port in 1996, 1997 and 2001

Photo 6.5.4 Shoreline around Pecém Port in 2001, 2004 and 2005

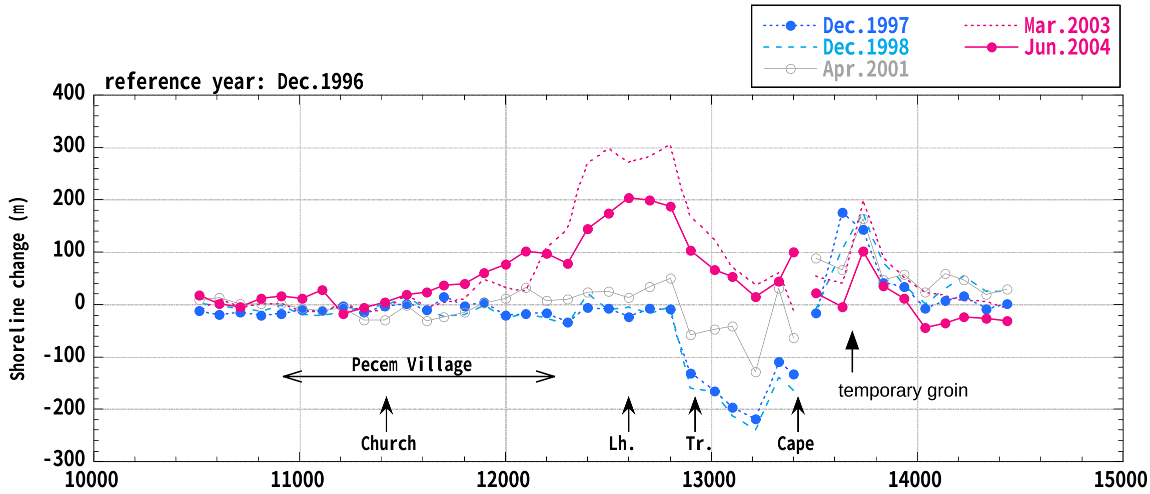


Figure 6.5.8 Shoreline Change Obtained by Monitoring Surveys from 1996 until 2004 (Reference Year 1996)

February 2001

August 2005

Photo 6.5.5 Comparison of Berm Height

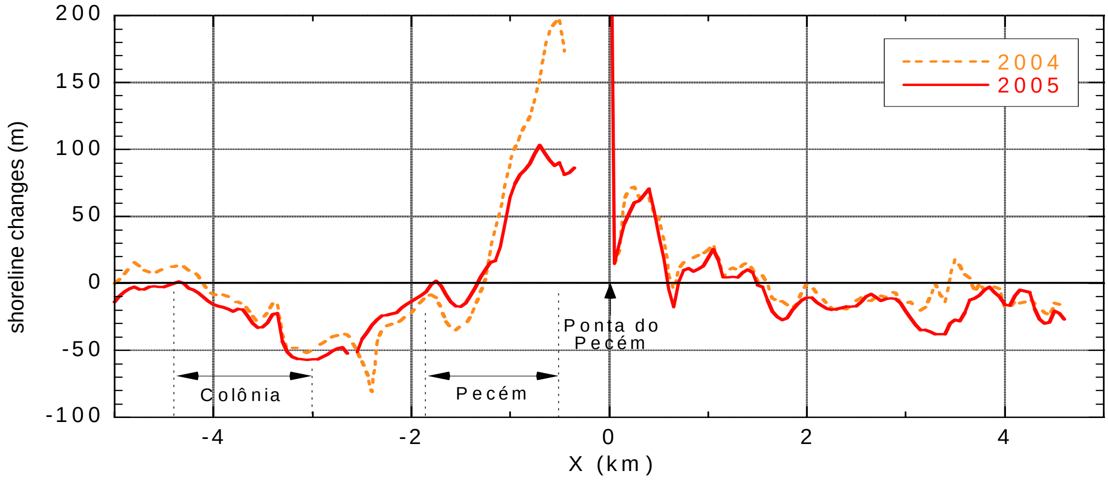


Figure 6.5.9 Shoreline Change (Reference Year 1987)

(3) Recurrence Analysis

A numerical computation method has been adopted to predict the change of coastline in the future. For this, it is important to check the accuracy of the recurrence between the computed and actual phenomena. The monitoring survey data gathered during the implementation work has been adopted as the recurrence data, because typical shoreline changes before, during and after construction of TEP was observed.

The numerical computation has been conducted using the newly improved multi contour line model (Serizawa, 2003[2)]). This model can consider not only alongshore sediment transport but also onshore-offshore sediment transport.

Figure 6.5.10 shows the result of the recurrence computation from the year of 1996 to 2001 with existence of TEP. Though some degree of difference between computed results and the measurements is observed at the down drift side, the computed result at on the up drift side agrees well with the measurements.

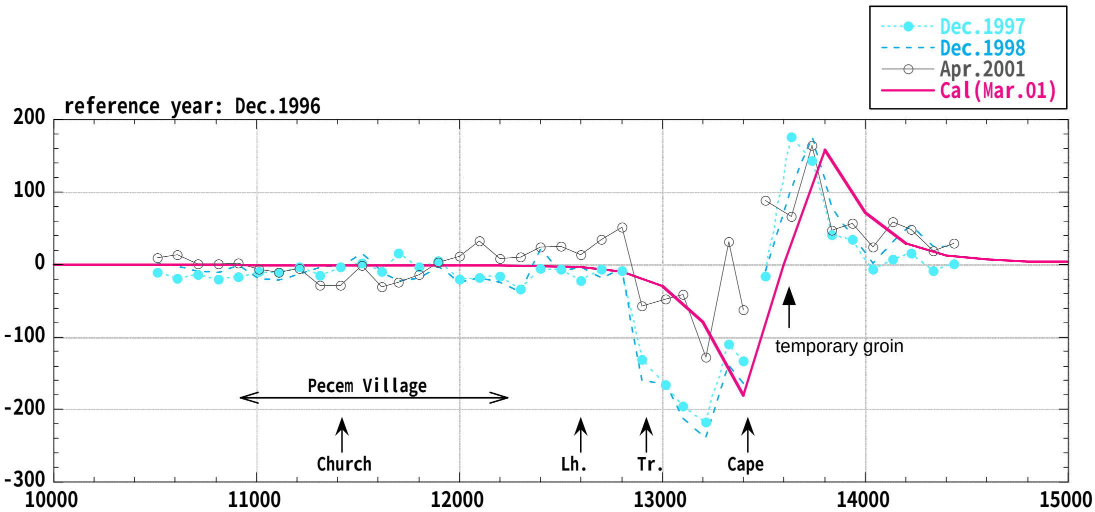


Figure 6.5.10 Comparison of Computed and Measured Shoreline Change (During Construction Period)

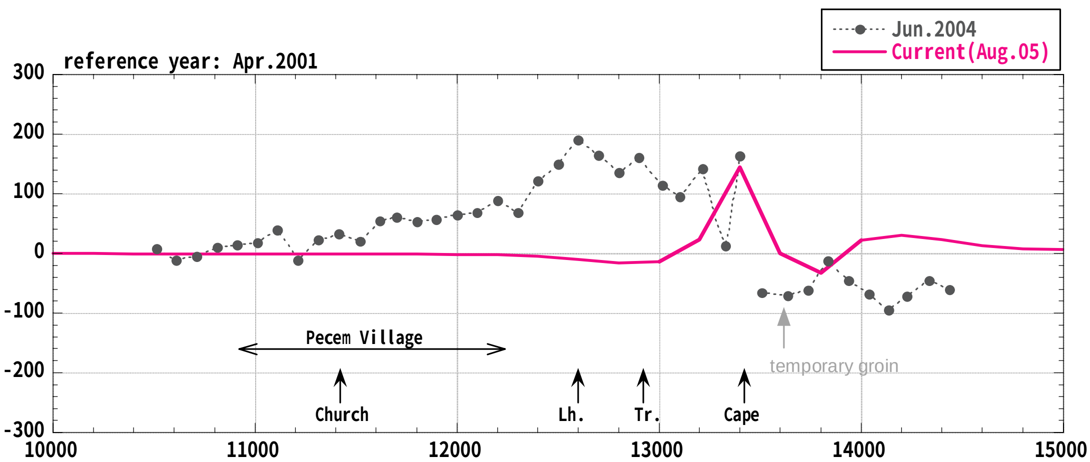


Figure 6.5.11 Comparison of Computed and Measured Shoreline Change (After Removal of TEP)

Figure 6.5.11 shows the predicted shoreline after removal of TEP. The tendency for the accumulated sand at the east side of TEP to move to the westward and accumulate behind the wave shadow region agrees well with observations. This result is a good model of the actual current phenomena caused near the Ponta do Pecém.

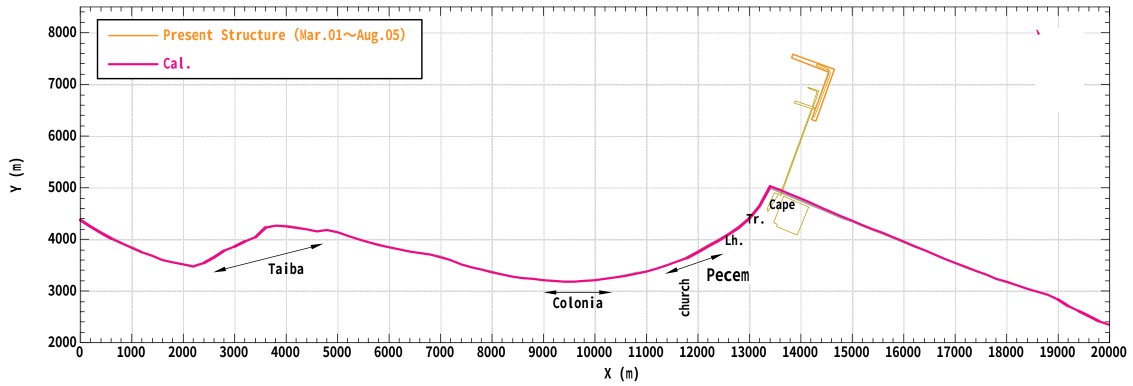
(4) Coastal Impacts from the Future Plan

The coastal impacts caused by the layout of the long-term development plan have been examined using the same numerical computation model. The point to consider is how to determine the impact of the layout of the long-term development plan compared to that from the layout of the existing port. Further, computations for an offshore breakwater type such as at Pecém Port and for a semi-infinite jetty type, which would extend from the landside, the same as TEP, or the breakwater at Mucuripe Port, have also been conducted to analyse the coastal impact due to the different breakwater layouts. In the numerical computation, 300,000 m3/year of littoral transport has been assumed as the boundary condition on the up-drift side. It is complicated to deal with the influence of the cape under the condition of dynamic equilibrium of littoral drift such as Pecém coast in the numerical modelling. Therefore, the numerical model has been simplified to omit the influence of the cape in order to analyse the influence of the layout of the breakwaters independently.

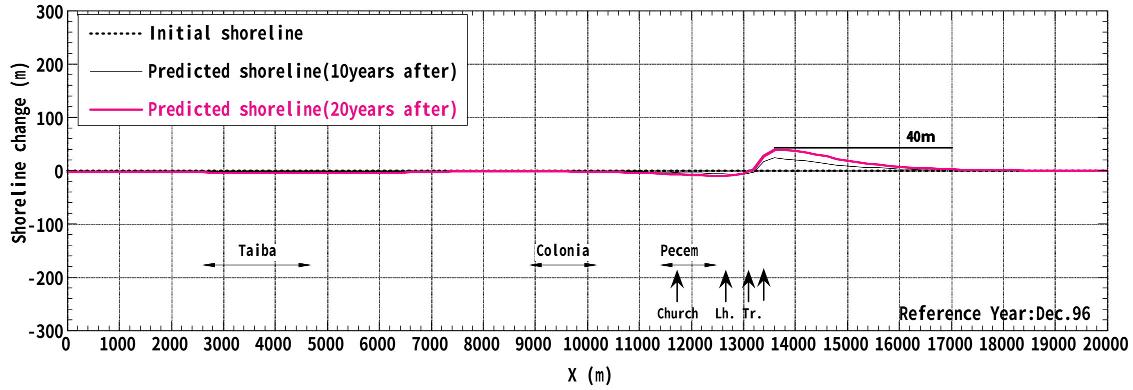
Figures 6.5.12 and 6.5.13 shows the predicted shoreline after 10 and 20 years for the layout of the existing port and the proposed future plan, respectively. The upper figure show the predicted shape of the shoreline, the middle shows the shoreline change based on the initial (present) shoreline and the lower shows the net annual littoral transport along the coastline.

- With the future plan, a large accumulation area is formed behind the offshore breakwater compared to the present layout. The shoreline change at the maximum accumulation point increases by about four times compared to the case of the existing port.
- This accumulation is caused by a decrease in the littoral transport rate due to a decrease of wave action in the shadow region. The decrease of the littoral transport rate is 13% for the existing port and 63% for the proposed future plan.
- The location where the maximum accumulation appears is shifted about 1.5km to the eastward.
- The retreat starts at the Pecém village for both cases, however, the change of shoreline for the future plan is greater with a 110 m maximum in 20 years.
- The retreat occurs continuously toward the down-drift side (west side) until Taiba, but the quantity of retreat decreases.

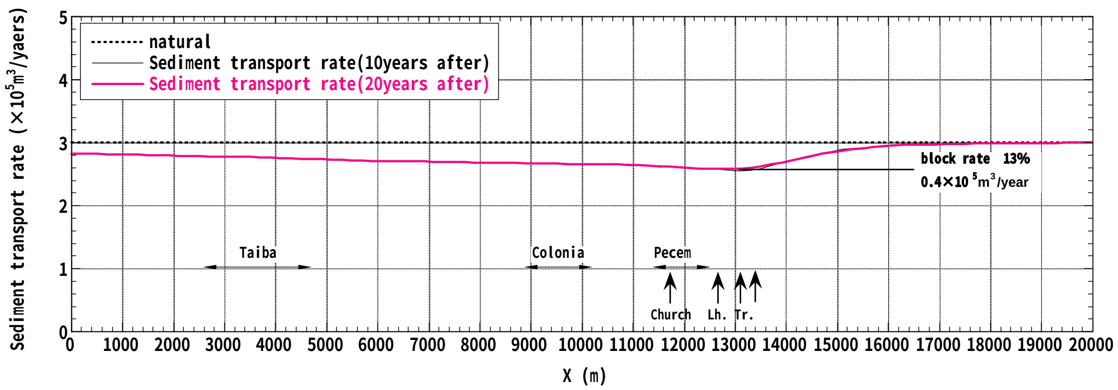
Figure 6.5.14 shows the comparison between the future plan and that of a semi-infinite jetty type breakwater the same as at Mucuripe Port. The shoreline change for the semi-infinite jetty type breakwater is significant with a maximum of 800m expected in 20 years because the westward littoral transport is completely intercepted by the jetty type breakwater. Therefore, even though the shoreline change for the proposed future plan is expected to be larger than that of the existing port due to expansion of the breakwater, this change of shoreline is much smaller than that for the semi-infinite jetty type breakwater as shown in Figure 6.5.14.



(1) Predicted Shape of Shoreline

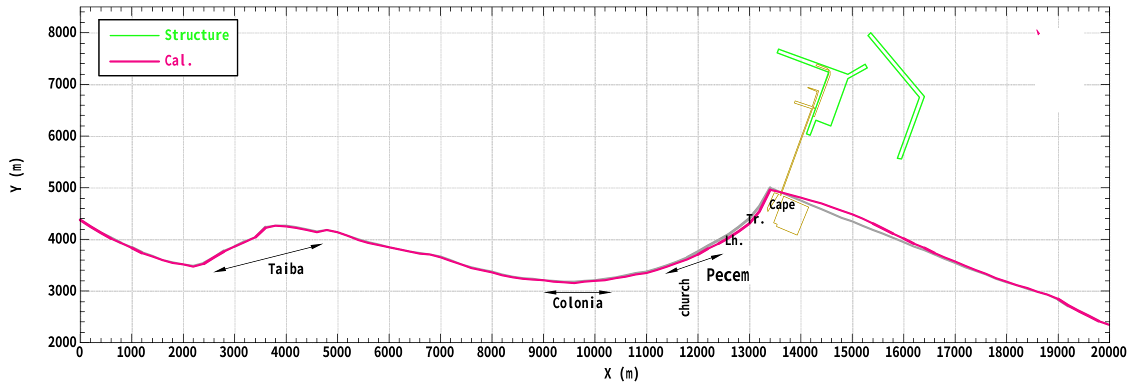


(2) Shoreline Change Based on the Initial (Present) Shoreline

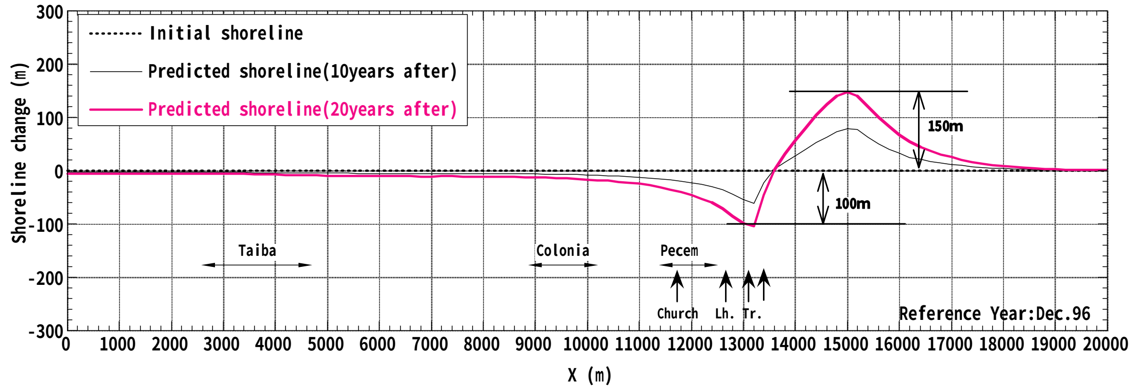


(3) Change of Littoral Transport Rate

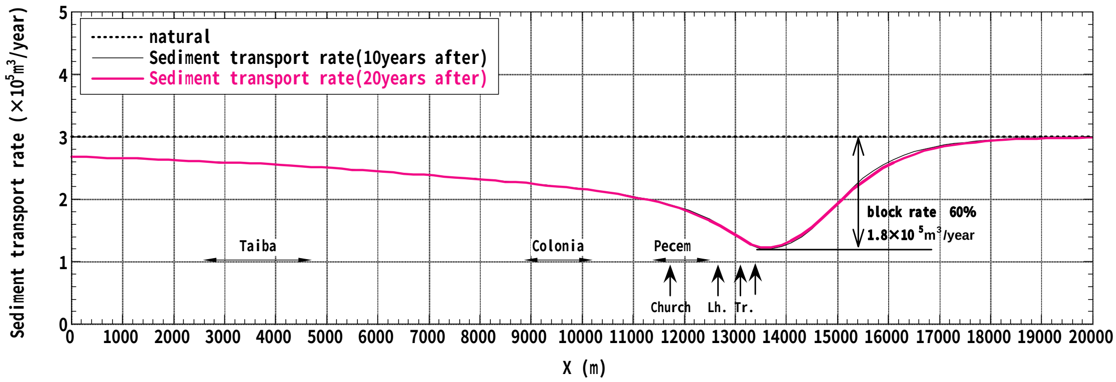
Figure 6.5.12 Predicted shoreline for the Existing Port Layout



(1) Predicted Shape of Shoreline



(2) Shoreline Change Based on the Initial (Present) Shoreline



(3) Change of Littoral Transport Rate

Figure 6.5.13 Predicted shoreline for Long Term Development Plan

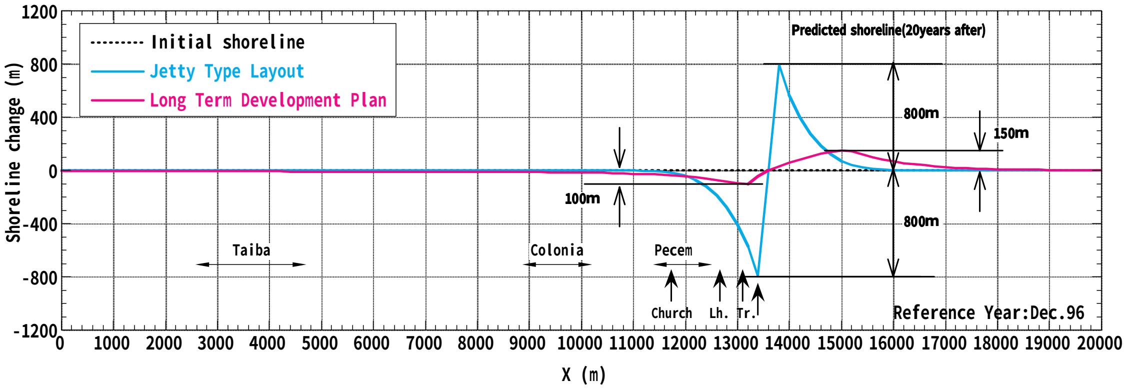


Figure 6.5.14 Comparison of Shoreline Change for Two Type of Breakwater (Proposed Future Layout and Jetty Type Breakwater)

Table 6.5.6 Sediment Balance for Each Port Layout

Layout	Net annual littoral transport (m3/year)		Sediment Loss due to Natural Conditions (m3/year)	Net Accumulation due to Existence of Port (m3/year)
	Up-Drift Side (East Side)	Down Drift Side (West Side)		
Without Port	280,000 - 360,000	240,000 - 320,000	40,000	0
Existing Port	280,000 - 360,000	210,000 - 280,000	40,000	30,000 - 40,000
Long-Term Development Plan	280,000 - 360,000	120,000 - 160,000	40,000	120,000 - 160,000
(ref.) Semi- infinite Breakwater (Same as Mucuripe Port)	280,000 - 360,000	0	-	280,000 - 360,000

Table 6.5.6 shows the sediment balance, which was estimated by both the numerical and data analysis, and Figures 6.5.15 and 6.5.16 show the images of sediment balance for the existing and future conditions. Before construction of the port facility, the coastline around Pecém was in dynamic equilibrium with net annual transport of about 280,000 to 360,000 m3/year at the east side of Ponta do Pecém and 240,000 to 320,000 m3/year at the west side, and no net accumulation existed. For the existing port, about 30,000 to 40,000 m3/year of net accumulation is estimated due to the sheltering effect of the port. Because of this and sediment loss due to natural conditions, the littoral transport at the west side (down drift side) from the accumulation area is decreased by about 24% (net littoral transport at down drift side is 210,000 to 280,000m3/year). For the long-term development plan, the net accumulation increases by about 120,000 to 160,000 m3/year, and further decrease of littoral transport at the west side occurs by about 63% (net littoral transport at the down drift side is 120,000 to 160,000 m3/year). For the semi-infinite jetty type, the westward littoral transport would be completely blocked and no littoral transport at the down side would exist.

Since the only actual influence from the existing port on the surrounding coast will be apparent now, it is important to continue the monitoring surveys to observe the behaviour of the shoreline around Pecém coast. After obtaining sufficient monitoring data, it is expected that it will be possible to predict the coastal impact for the future condition with high accuracy.

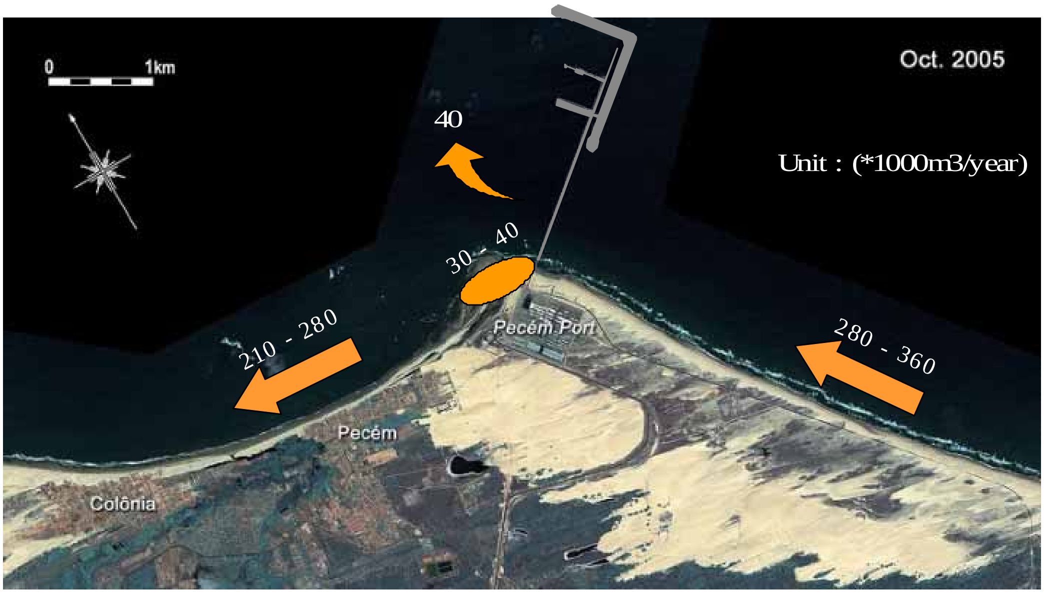


Figure 6.5.15 Image of Predicted Sediment Balance for the Existing Port

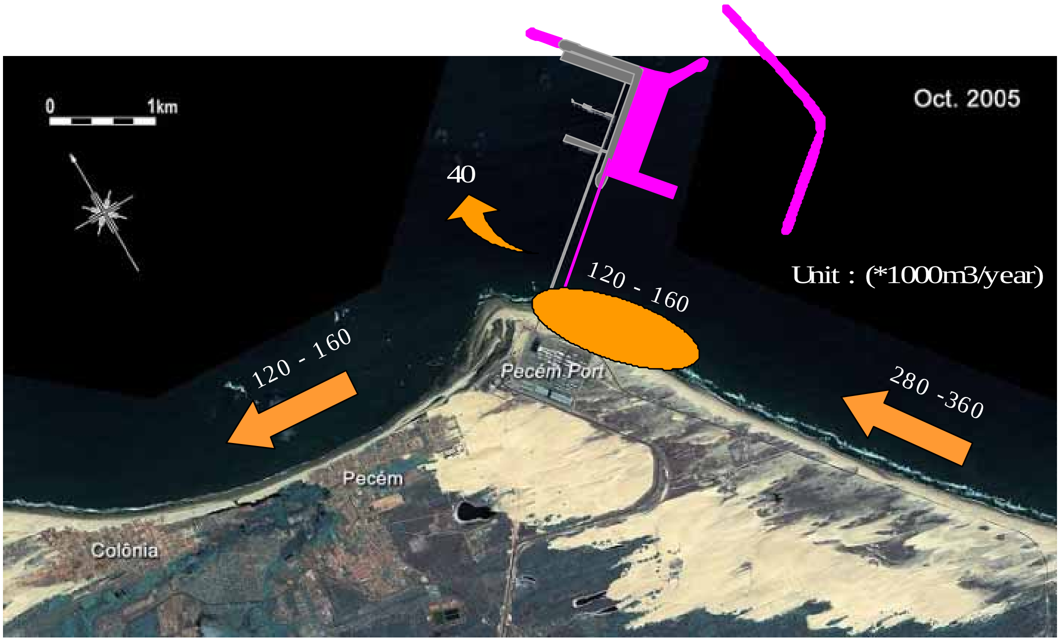


Figure 6.5.16 Image of Predicted Sediment Balance for Future Conditions

6.5.4 Possibility of Sedimentation in Port Basin

Bathymetric surveys have been conducted by INPH beginning before the construction of Pecém port. Using these data, the possibility of sedimentation at the port basin after construction of the breakwaters was examined. The survey results conducted in May 1999 (during implementation work), March 2003 (about two years after completion) and October 2004 (about three years after completion) were compared.

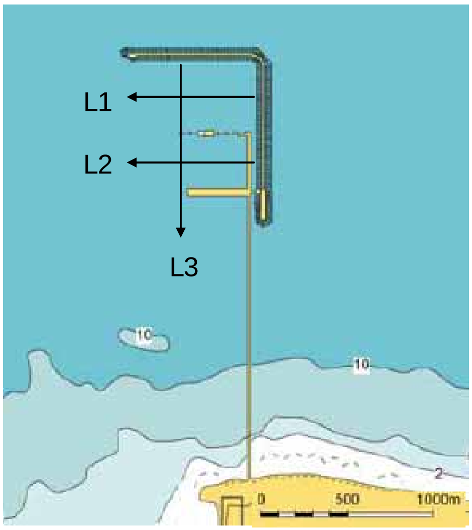


Figure 6.5.17 Examination Line

The three representative lines were established in the port area for the comparison as shown in Figure 6.5.17. Figure 6.5.18 shows the results for each line. No significant sedimentation was observed after completion of the breakwaters. These data suggest that the average depth after completion become slightly deeper than that during the implementation period. Though it cannot be clarified whether this actually happened or was due to slight inaccuracies in field measurement, it can be said that the sedimentation hasn't occurred.
The critical water depth for sediment is estimated by using following formula presented by Sato (1962)[3)].

$$\frac{H_0}{L_0} = \alpha \left(\frac{d}{L_0} \right)^n \left(\sinh \frac{2\pi\, hi}{L} \right) \frac{H_0}{H}$$

Here, H_0 : Offshore Wave Height

L_0 : Offshore Wave Length
d : Mean Grain Size for the Sediment
h_i : Critical Depth for Sedimentation
H : Wave Height
L : Wave Length

Various coefficients of α in this formula have been proposed according to movement form including initial movement, general movement, net transport of surface sediment and net transport of all sediment. Among these, the critical depth for net transport of both surface sediment and all sediment is important from the engineering point of view, because they cause significant bottom change. By using the characteristics of waves and sand at Pecém, the critical water depth for sediment was estimated as about 9m for net transport of surface sediment and 5m for net transport of all sediment.

Another formula to estimate the critical water depth for sediment was proposed by Uda et.al (2002) based on the collected field data for waves and topography as below.

$$h_i = 3.64 H_{5\%}$$

Here, $H_{5\%}$ is the 5% exceedance wave height. From the distribution of wave height shown in Table 3.2.3 in Chapter 3, H_{95} is estimated as 1.83m. Using above formula, the critical water depth for sediment was estimated as about 6.7m.

The average depths at pier No. 1 and No. 2 are about 15.5m and 16.5m, respectively, and this is far deeper than the critical water depth for sediment movement. For this reason, it can be said that the probability of remarkable sedimentation in the basin is quite low as long as the depth of the basin remains at the same level as the present basin. However, there is a possibility of sedimentation if the basin depth changes to become near the critical water depth for sediment movement, or, the shadow region for waves becomes wider due to the construction of a long breakwater due to the settlement of the suspended load in the shadow region for waves. From the results of bottom sampling which were conducted by the JICA Study Team, it was observed that silt and mud were deposited at all sampling points in the basin.

[References]

1) Ishii,T., M. Isobe and A. Watanabe: ” Improved boundary conditions to a time-dependent mild-slope equation for random waves”, Proc. 24th Int. Conf. on Coastal Eng., 1994 pp.272-284

2) Serizawa, M. et al: ” Improvement of contour line change model in terms of stabilization mechanism of longitudinal profile”, Coastal Sediments, 2003, pp.1-15.

3) Shoji SATO: ”A Study of littoral drift related to harbour construction”, Tech. Note of PHRI, No.5,1962,156p. (in Japanese)

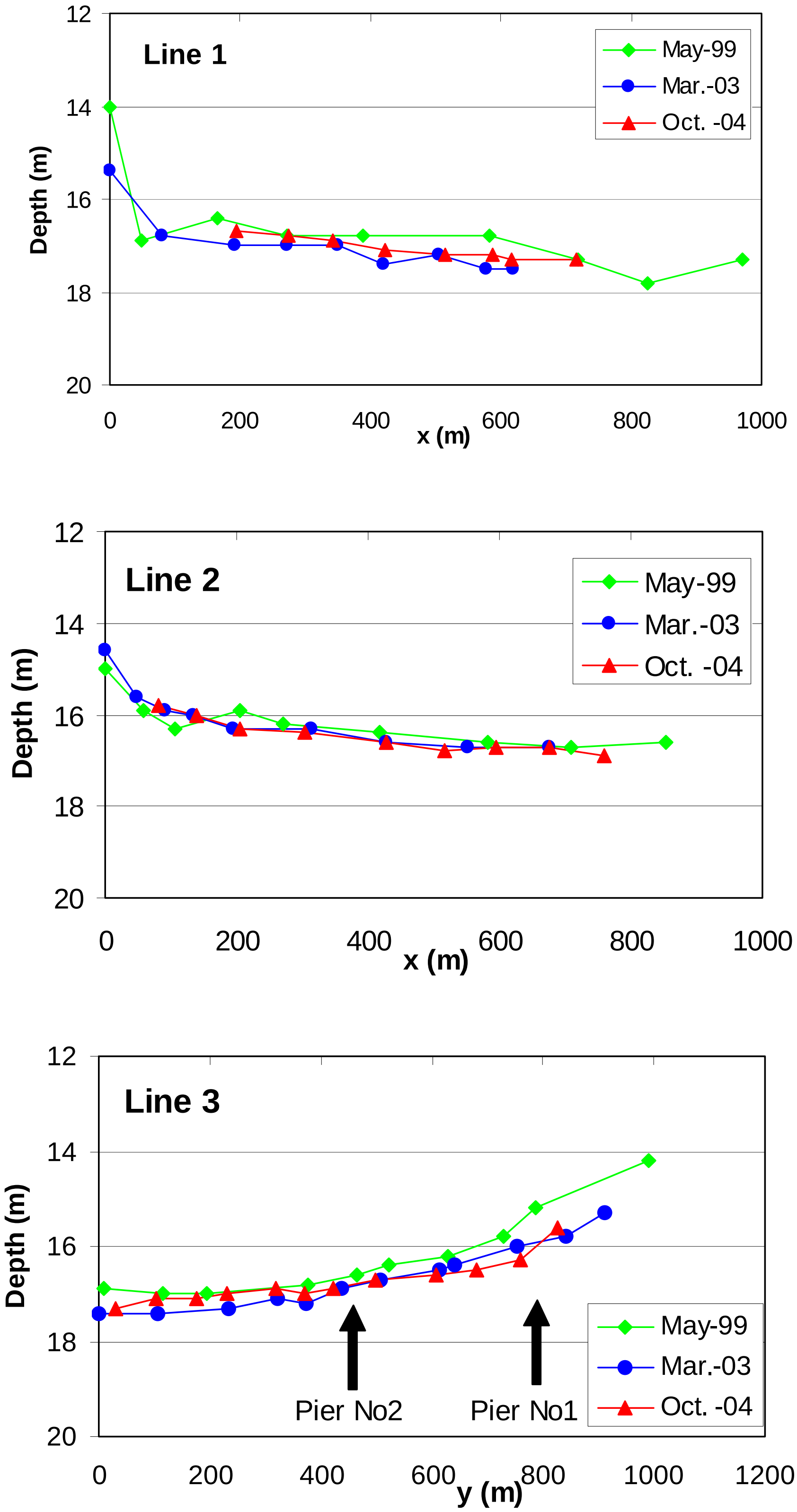


Figure 6.5.18 Comparison of Depth Change for Each Line