SUMMARY

This summary covers the key items presented in CHAPTERS V through XII of the study.

I CURRENT PROBLEMS AND STUDY OBJECTIVES

The Port of Caldera has recently experienced such serious problems as sand sedimentation in the harbour, insufficient berth length and inefficient cargo handling. The problems affecting the Port of Caldera must be solved so that the port can fulfill its role as the main international gateway on the Pacific coast of Costa Rica. The current problems facing the port and the study objectives are summarized below.

1. Sand Sedimentation

There is sand drift along almost the entire east coast of Nicoya Bay. Measures must be taken to protect the Port of Caldera from sand drift and sedimentation. To put it concretely, the average annual sand sediment volume for the last three years is approximately 100,000 to 110,000 m^3. The rate of sedimentation at the harbour side of the breakwater has been accelerating.

Particularly, the edge of the sediment at the harbour side of the breakwater has reached the −11 m quaywall. The berth area for the said quaywall has shoaled along a distance of about 100 m. Thus, large vessels of the design ship size are not able to load or unload cargoes at the wharf at present.

2. Insufficient Berth Size

The total berth length is 490 m, but the berth length where large vessels (15,000 to 20,000 DWT) can berth is only 360 m. Especially, the present berth length of the −10 m quaywall is short. Thus, at present, only one large vessel can berth at the Port of Caldera at one time. However, the port must have appropriate facilities to accomodate two vessels such as one container ship and one grain cargo carrier simultaneously.

3. Necessity of Improving the Cargo Handling Systems

The Port of Caldera handles a great variety of commodities and has a relatively large throughput with a small number of berths. This situation will develop further along with the increase of port cargo in the future. Particularly, the Port of Caldera will be obliged to handle imported grain which is currently handled at Puntarenas pier. Thus, it is necessary to improve the existing cargo handling system for multipurpose use of the terminal at the

4. Expected Port Functions and Study Objectives

The Port of Caldera is expected to function as the main international gateway on the Pacific coast. However, the port has experienced such serious problems as (1) sand sedimentation, (2) insufficient berth length and (3) inefficient cargo handling systems as noted above. The countermeasures to solve problem (1) will restore the potential capacity of the port. The countermeasures to solve problems (2) and (3) are means to enhance the existing port capacity by improving existing facilities and equipment. The capacity restored and enhanced by the above countermeasures must, of course, be maintained well even after these countermeasures are implemented.

Therefore, the study seeks to restore the potential port capacity, to enhance the port capacity by improving existing facilities and adding needed equipment, and to maintain the enhanced port capacity by procuring appropriate machinery and devising an appropriate maintenance system so that the port can function to the utmost of its potential. Thus, the study covers not only how to execute the primary construction work itself, but also how to execute the regular maintenance work after the primary construction work is completed. The composition of the study is shown in Table 1.

Table 1 Problems and Countermeasures

Problems	Countermeasures			Related CHAPTER in this report
	Restoration	Improvement	Maintenance	
(1) Sand sedimentation	○		○	VI, IX
(2) Insufficient berth length		○		VII
(3) Inefficient cargo handling		○	○	VIII

If proper countermeasures are properly implemented to solve these problems, the Port of Caldera will be able to fulfill its role as the main international gateway on the Pacific coast.

II COUNTERMEASURES AGAINST SAND SEDIMENTATION

1. Present Conditions

The past and present field surveys reveal some characteristic features of the sand drift and sedimentation around the Port of Caldera. The sand sedimentation in the harbour basin is caused by two distinct phenomena. The drift sand from New Beach moves around the head of the breakwater, goes toward the foot of the breakwater, and accumulates around there due to the wave action and the longshore current. This is one cause of the harbour sedimentation. The other phenomenon is the sedimentation of the entire basin with almost a uniform thickness. This is mainly caused by the wave action and the tidal current.

The sand sediment volume over a recent five year period is shown in Table 2.

Table 2 Sand Sediment Volume

Period	Sand Sediment Volume(m^3)		
	Harbour Side of the Breakwater	Turning Basin	Total
1980' 4 ~1981'10	12,000	—	—
1981'10~1982' 7	21,000	−26,000	−5,000
1982' 7 ~1983' 8	40,250	70,813	111,063
1983' 8 ~1984' 8	24,125	77,938	102,063
1984' 8 ~1985' 9	94,500*)	18,250	112,750

Note: *) This volume includes the dredged sand volume.

The first phenomenon is the littoral drift around the breakwater. The sand drift pattern at the southern beach of the breakwater is shown in Fig. 1. The littoral drift volume and also the sand sediment volume at the harbour side of the breakwater becomes greater as the seaside water depth of the breakwater becomes shallower. Fig. 2 shows the relation between D and Q_s. D is the distance between the head of the breakwater and the −2 m contour line in meters. Q_s is the annual sand sediment volume at the harbour side of the breakwater (m^3/year). The figure shows that the Q_s is determined only from the D value. When D is more than 60 m, Q_s is zero. If D becomes shorter, then Q_s becomes greater. Finally, Q_s approaches asymptotically to 112,000 m^3/year, that is the sum of the littoral drift volume at Corralillo Beach and New Beach.

In the harbour basin, there is also the other type of sedimentation, that is the accumulation of fine sand with an almost uniform thickness. The median grain diameter of this sediment sand is around 0.1 mm. This sediment is transported by the tidal current and the longshore current. The sand sediment rates and the annual sediment volume in the basin are shown in Fig. 3.

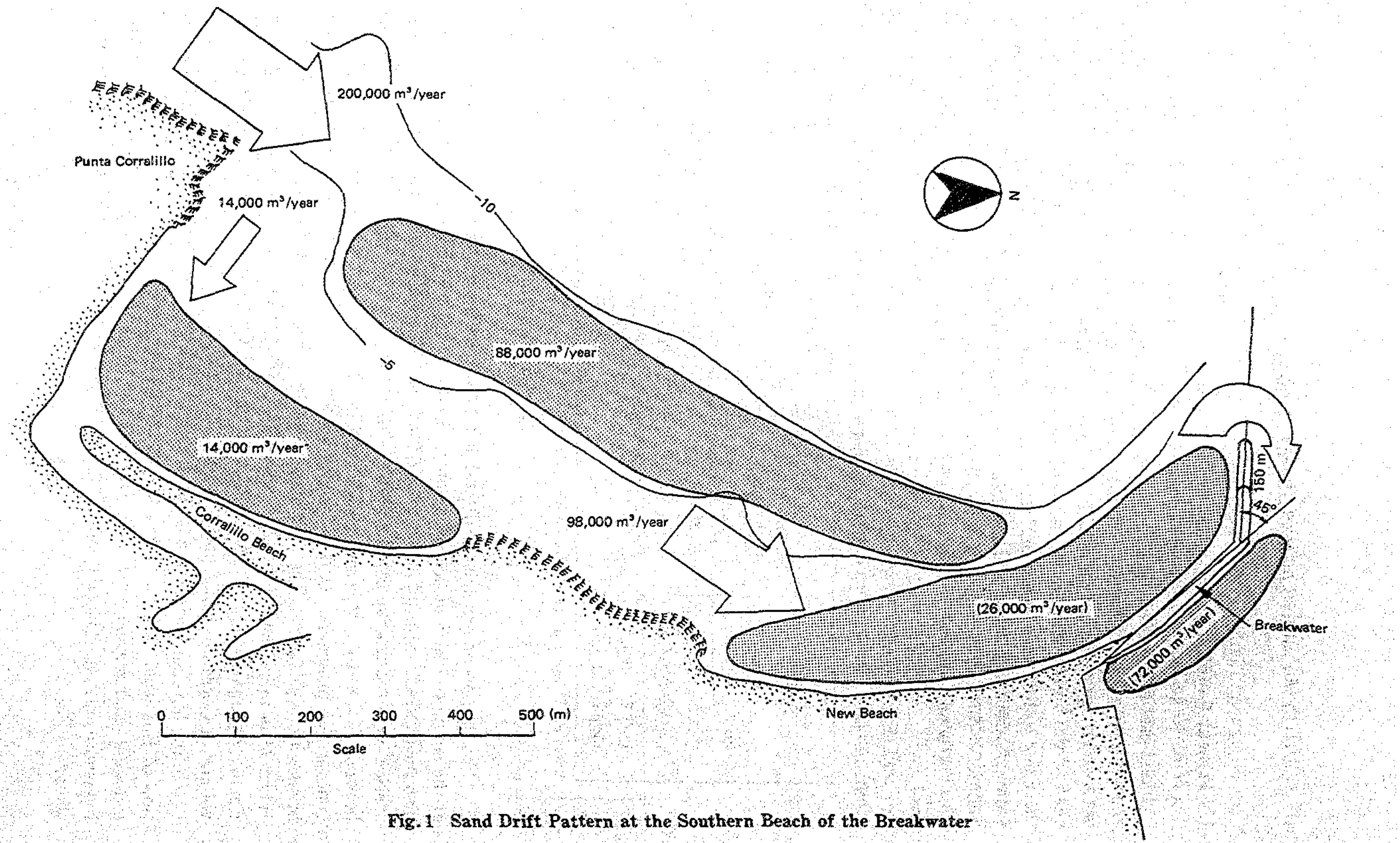


Fig. 1 Sand Drift Pattern at the Southern Beach of the Breakwater

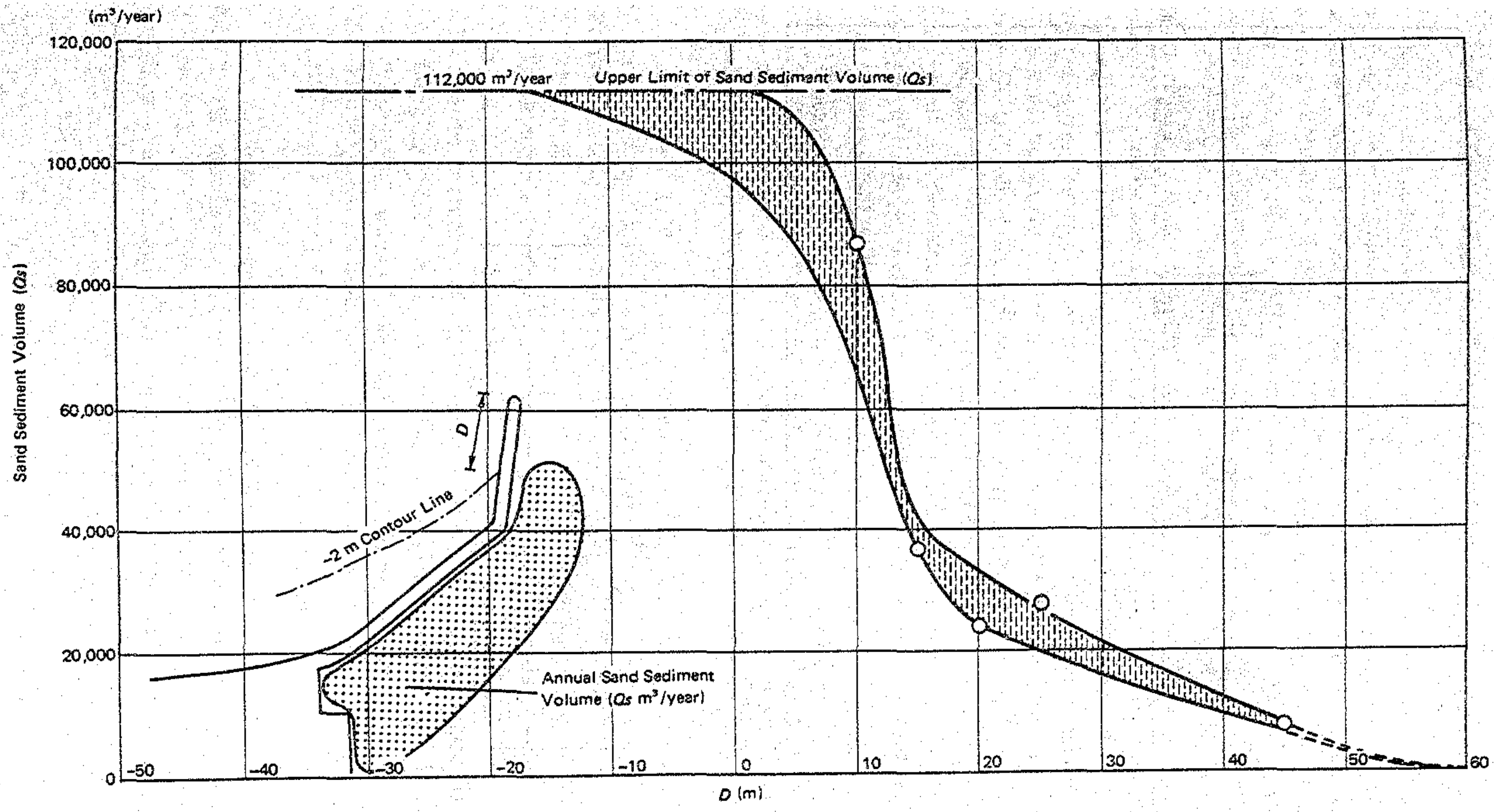
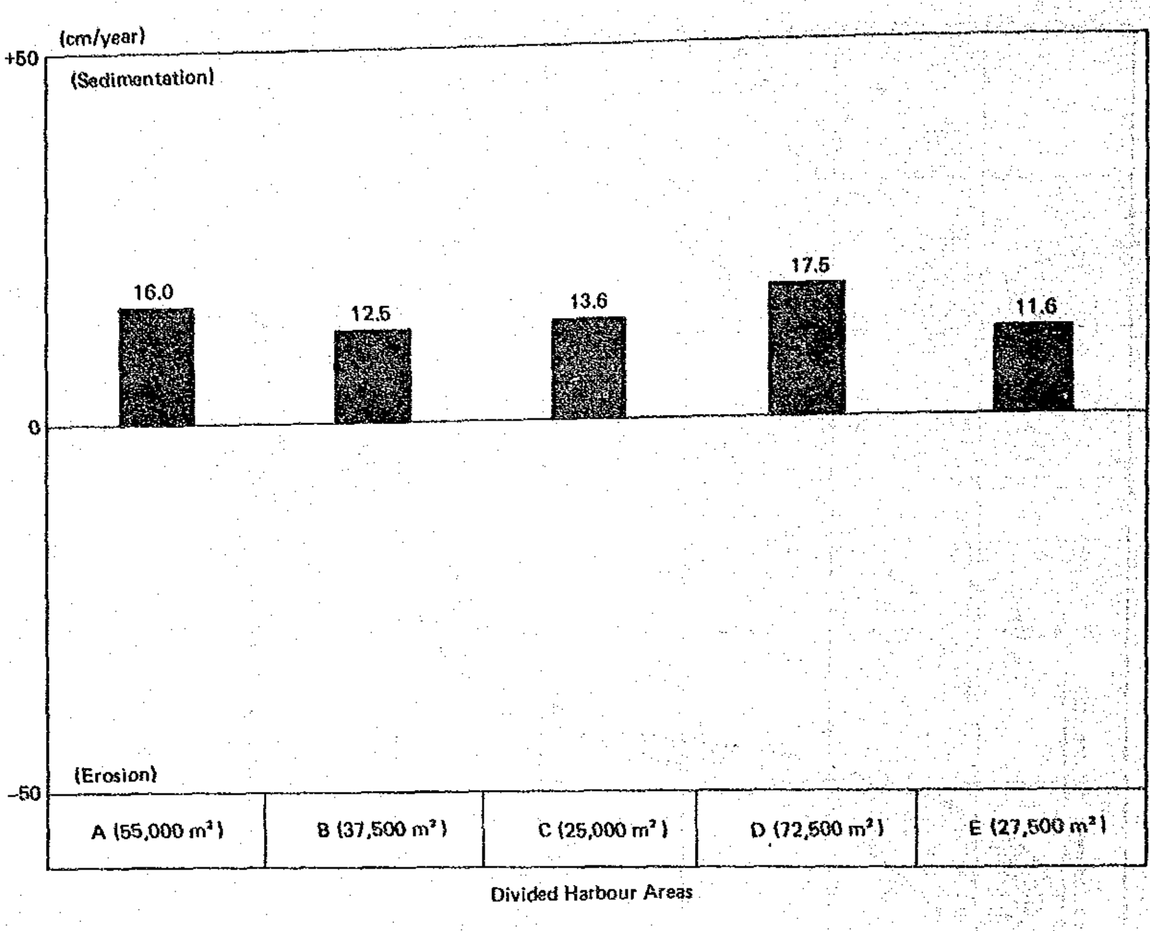


Fig. 2 Relation between D and Q_s



Zone	Area (m^2)	Annual Sediment Rate (m/year)	Annual Sediment Volume (m^3/year)
A	55,000	0.160	8,800
B	37,500	0.125	4,700
C	25,000	0.136	3,400
Total	117,500	–	16,900

Fig. 3 Annual Sediment Rate and Sediment Volume

2. Future Estimation of the Sand Sedimentation

Future sand sedimentation in the harbour is estimated by simulations using mathematical models. For the simulations, it is most important to select appropriate models which accurately reflect the sand sedimentation mechanisms. For the estimation of the sand sedimentation at the harbour side of the breakwater, the 'One-Line Theory' is the most suitable mathematical model. On the other hand, the 'Depth Model' is the most suitable model for the estimation of the sand sedimentation in the entire harbour basin.

Fig. 4 and Fig. 5 show the results of the reconstruction of the shoreline change at New Beach and of the water depth change in the harbour basin respectively using the simulation models. It can be seen from these figures that the calculation results using the 'One-Line Theory' and the 'Depth Model' conform with the actual conditions. Therefore, these models can reasonably be applied for the estimation of the future sand sedimentation.

Some alternative countermeasures against sand sedimentation are proposed in this study. As a result of the evaluation of the various alternatives, the alternative involving the extension of the breakwater along the same center line as the existing breakwater and the dredging of unavoidable sediment in the harbour is recommended as the best plan. Of course, the removal of the sand at the south of Mata de Limón Inlet by INCOFE should be continued as at present along with the implementation of the recommended plan.

The length of the additional breakwater extension is determined so as to minimize the total of the dredging cost and the breakwater construction cost. The dredging costs under each alternative breakwater extension plan including the case where the breakwater is not extended at all are estimated based on the estimation of the required dredging volume under each plan.

Table 3 and Table 4 show the results of the future estimation of the sand sedimentation by the 'One-Line Theory' and the 'Depth Model', respectively. Table 5 shows the total dredging volume over 30 years, which is the lifetime of the project, for each breakwater extension length.

These dredging volumes are estimated under the following premises.

(1) The 150 m breakwater extension from the corner of the existing breakwater (a part of the wing jetty) is completed by May 1986. (The Japanese Study Team has given some information to MOPT concerning the immediate breakwater extension works.)

(2) The 300,000 m^3 of sediment sand in the basin is dredged by a foreign contractor by May 1986.

Fig. 6 shows the breakwater construction costs, the dredging costs and the total costs of each breakwater extension length over 30 years including the case where the breakwater is not extended at all. From this figure, it is clear that the most economical countermeasure against sand sedimentation in the harbour basin is to extend the breakwater by a length of 200 m.

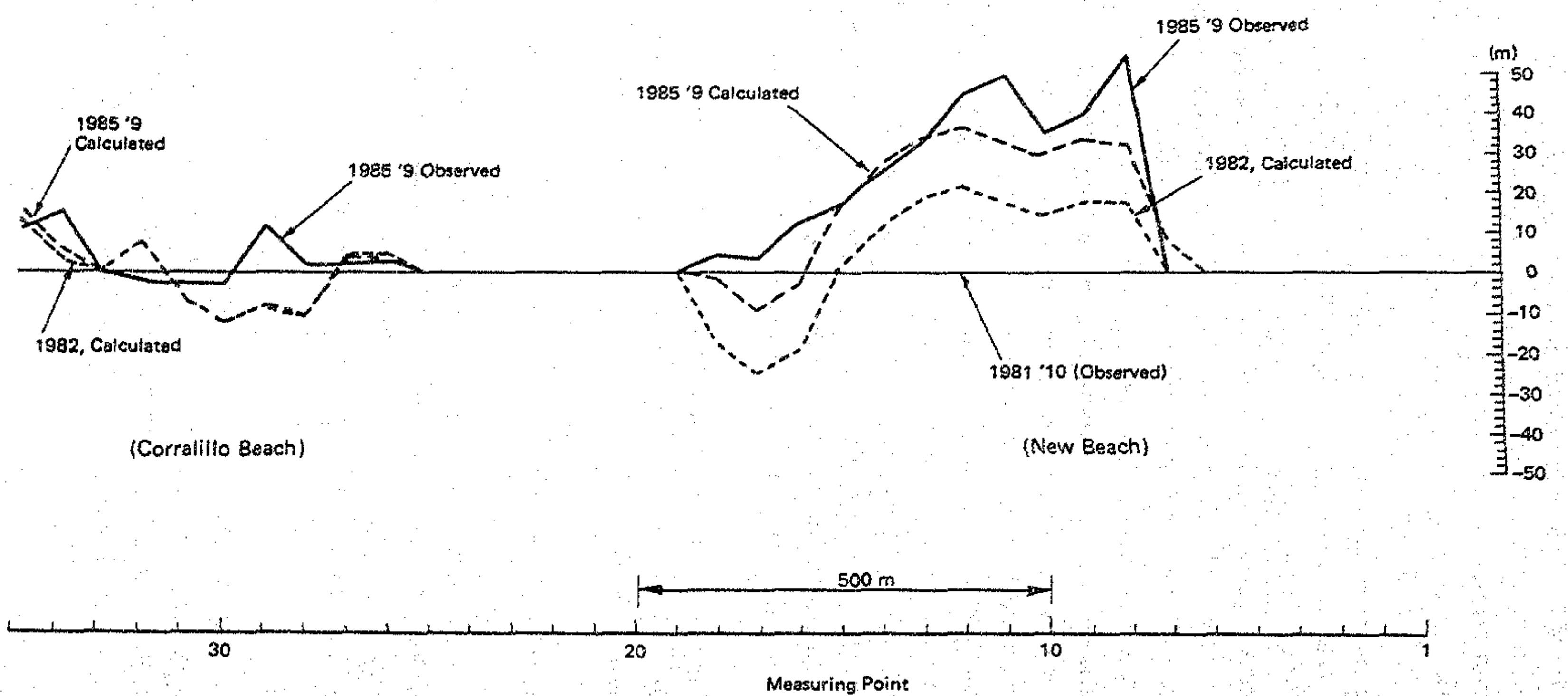
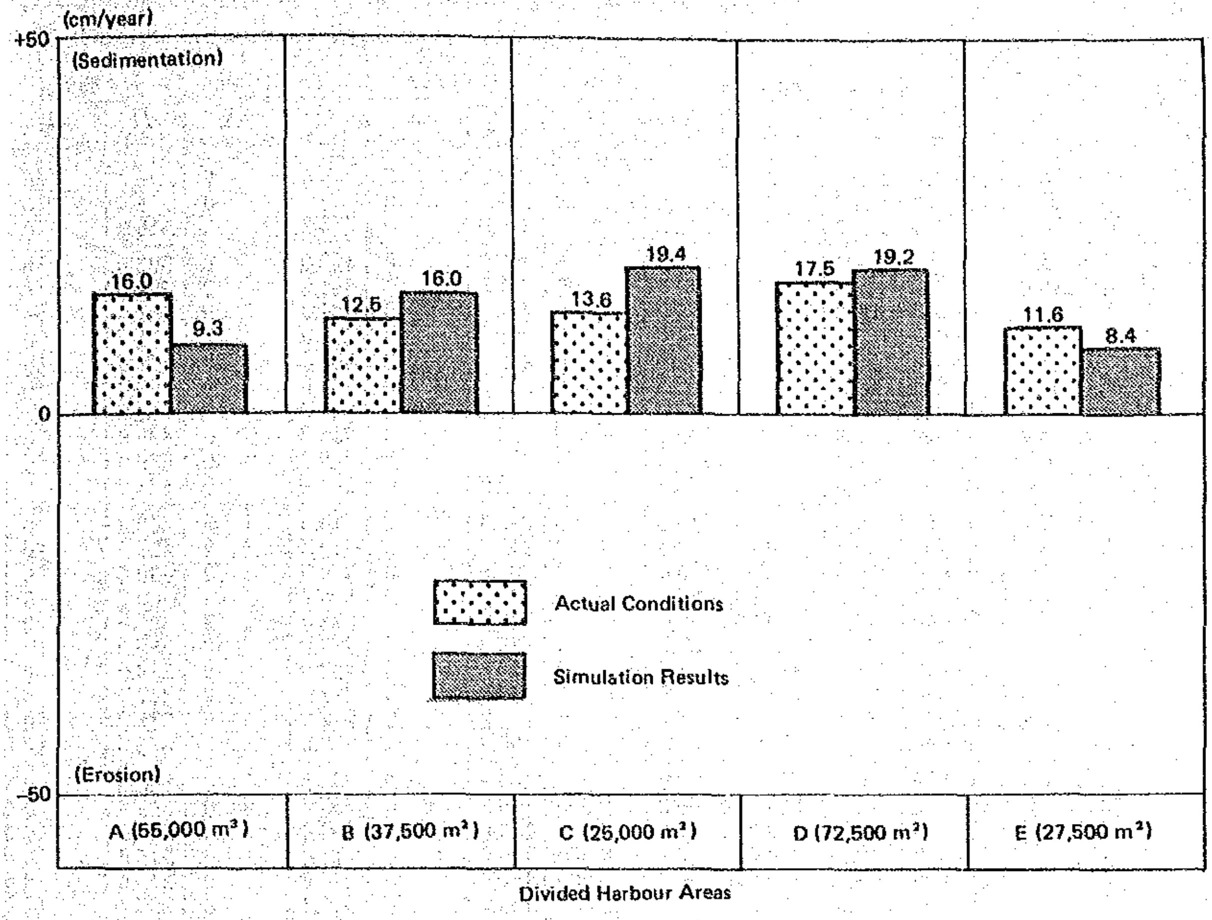


Fig.4 Simulation Result by One-Line Theory
(Reconstruction of the Actual Shoreline Change)



Zone	Area (m^2)	Actual or Simulation	Annual Sediment Rate (m/year)	Annual Sediment Volume (m^3/year)
A	55,000	Actual Conditions	0.160	8,800
		Simulation Results	0.093	5,100
B	37,500	Actual Conditions	0.125	4,700
		Simulation Results	0.160	6,000
C	25,000	Actual Conditions	0.136	3,400
		Simulation Results	0.194	4,900
Total	117,500	Actual Conditions	–	16,000
		Simulation Results	–	16,900

Fig. 5 Reconstruction of the Depth Change

Table 3 D and Q_s of Each Year

Year	Case 1 L=0m		L=100m		Case 2 L=200m		Case 3 L=300m		Case 4 L=400m		L=500m	
	D (m)	Q_s (m³/year)	D (m)	Q_s (m³/year)	D (m)	Q_s (m³/year)	D (m)	Q_s (m³/year)	D (m)	Q_s (m³/year)	D (m)	Q_s (m³/year)
Jan., 1988	35.4	15,000	135.0	0	—	0	—	0	—	0	—	0
9	31.0	19,000	129.0	0	228.0	0	328.0	0	—	0	—	0
1990	26.9	25,000	123.9	0	215.0	0	315.0	0	415.0	0	515.0	0
1	23.1	31,000	118.3	0	203.0	0	303.0	0	403.0	0	503.0	0
2	19.6	37,000	112.5	0	191.0	0	291.0	0	391.0	0	491.0	0
3	16.8	48,000	106.6	0	181.0	0	281.0	0	381.0	0	481.0	0
4	14.5	58,000	100.7	0	171.0	0	271.0	0	371.0	0	471.0	0
5	12.5	66,000	95.0	0	162.0	0	262.0	0	362.0	0	462.0	0
6	10.8	72,000	89.3	0	153.0	0	253.0	0	353.0	0	453.0	0
7	9.3	77,000	83.6	0	144.0	0	244.0	0	344.0	0	444.0	0
8	8.0	82,000	77.9	0	135.0	0	235.0	0	335.0	0	435.0	0
9	6.8	85,000	72.2	0	129.0	0	229.0	0	329.0	0	429.0	0
2000	5.8	88,000	66.5	0	123.9	0	223.9	0	323.9	0	423.9	0
1	4.8	91,000	60.8	0	118.3	0	218.3	0	318.3	0	418.3	0
2	4.0	93,000	55.3	3,000	112.5	0	212.5	0	312.5	0	421.5	0
3	3.3	96,000	50.0	5,000	106.6	0	206.6	0	306.6	0	406.6	0
4	2.6	98,000	45.0	8,000	100.7	0	200.7	0	300.7	0	400.7	0
5	2.1	99,000	40.0	10,000	95.0	0	195.0	0	295.0	0	395.0	0
6	1.5	101,000	35.4	15,000	89.3	0	189.3	0	289.0	0	389.0	0
7	1.1	103,000	31.0	19,000	83.6	0	183.6	0	283.0	0	383.0	0
8	0.8	105,000	26.9	25,000	77.9	0	177.9	0	277.9	0	377.9	0
9	0.4	107,000	23.1	31,000	72.2	0	172.2	0	272.2	0	372.2	0
2010	0.1	109,000	19.6	37,000	66.5	0	166.5	0	266.5	0	366.5	0
1	−0.3	112,000	16.8	48,000	60.8	0	160.8	0	260.8	0	360.5	0
2		112,000	14.5	58,000	55.3	3,000	155.3	0	255.3	0	355.5	0
3		112,000	12.5	66,000	50.6	5,000	150.0	0	250.0	0	350.0	0
4		112,000	10.8	72,000	45.0	8,000	145.0	0	245.0	0	345.0	0
5		112,000	9.3	78,000	40.0	10,000	140.0	0	240.0	0	340.0	0
6		112,000	8.0	82,000	35.4	15,000	135.4	0	235.4	0	335.4	0
7		112,000	6.8	85,000	31.0	19,000	131.0	0	231.0	0	331.0	0
8		112,000	5.8	88,000	26.9	25,000	126.9	0	226.9	0	326.9	0
9		112,000	4.8	91,000	23.1	31,000	123.1	0	223.1	0	323.1	0
2020		112,000	4.0	93,000	19.6	37,000	119.8	0	219.8	0	319.6	0
1			3.3	96,000	16.8	48,000	116.8	0	216.8	0	316.8	0
2			2.6	98,000	14.5	58,000	111.5	0	211.5	0	311.5	0
3			2.1	99,000	12.5	66,000	106.1	0	206.1	0	306.1	0
4			1.5	101,000	10.8	72,000	100.8	0	200.8	0	300.8	0
5			0.8	105,000	9.3	78,000	95.4	0	195.4	0	295.4	0
6			0.4	107,000	8.0	82,000	90.1	0	190.1	0	290.1	0
7			0.1	109,000	6.8	85,000	84.7	0	184.7	0	284.7	0
8			−0.3	112,000	5.8	88,000	79.4	0	179.4	0	279.4	0
9				112,000	4.8	91,000	74.0	0	174.0	0	274.0	0
2030				112,000	4.0	93,000	68.7	0	168.7	0	268.7	0
1				112,000	3.3	96,000	63.3	0	163.3	0	263.3	0
2				112,000	2.6	98,000	58.1	1,000	158.1	0	258.1	0
3				112,000	2.1	99,000	53.2	4,000	152.8	0	252.8	0
4				112,000	1.5	101,000	48.4	6,000	147.7	0	247.7	0
5				112,000	0.8	105,000	43.7	8,000	142.6	0	242.6	0
6				112,000	0.4	107,000	39.2	11,000	137.7	0	237.7	0
7				112,000	0.1	109,000	34.9	15,000	132.7	0	232.7	0
8				112,000	−0.3	112,000	30.9	19,000	127.7	0	227.7	0
9				112,000		112,000	27.1	25,000	122.7	0	222.7	0
2040				112,000		112,000	23.5	30,000	117.7	0	217.7	0
1						112,000	20.2	35,000	112.2	0	212.2	0
2						112,000	17.5	45,000	107.7	0	207.7	0
3						112,000	15.2	54,000	102.7	0	202.7	0
4						112,000	13.3	62,000	97.7	0	197.7	0
5						112,000	11.6	69,000	92.7	0	192.7	0

Notes : 1) D is the distance between the head of the breakwater and the −2.0m contour line at the start of each period (m).
2) Q_s is the annual sand sediment volume (m³/year).
3) D and Q_s in the cases of L=100m and L=500m are assumed complementing the simulation results.

Table 4 Simulation Results (Depth Model)

Case	Sedimentation Rates	Divided Harbour Area						
		A(55,000m²)	B(37,500m²)	C(25,000m²)	Sub Total (117,500m²)	D(72,500m²)	E(27,500m²)	Total (217,500m²)
Actual Conditions	Depth Change (cm/year)	16.0	12.5	13.6	—	17.5	11.6	—
	Annual Sediment Volume(m³/year)	8,800	4,700	3,400	16,900	12,700	3,200	32,800
Case 1 Reconstruction of the Actual Conditions	Depth Change (cm/year)	9.3	16.0	19.4	—	19.2	8.4	—
	Annual Sediment Volume(m³/year)	5,100	6,000	4,900	16,000	13,900	2,300	32,200
Case 2 Breakwater Extension L=200m	Depth Change (cm/year)	8.0	10.4	13.0	—	17.8	9.0	—
	Annual Sediment Volume(m³/year)	4,400	3,900	3,300	11,600	12,900	2,500	27,000
Case 4 Breakwater Extension L=400m	Depth Change (cm/year)	5.6	7.2	9.3	—	16.9	6.3	—
	Annual Sediment Volume(m³/year)	3,100	2,700	2,300	8,100	12,300	1,700	22,100

Table 5 Total Amount of Dredging Volume for 30 Years

Breakwater Extension Length	Primary or Maintenance Dredging	Dredging Volume (m³)		
		Harbour Side of the Breakwater	Harbour Basin	Total
0m	Primary Dredging	0	0	0
	Maintenance Dredging	2,571,000	544,000	3,115,000
	Total	2,571,000	544,000	3,115,000
100m	Primary Dredging	72,000	0	72,000
	Maintenance Dredging	642,000	465,000	1,107,000
	Total	714,000	465,000	1,179,000
200m	Primary Dredging	72,000	0	72,000
	Maintenance Dredging	41,000	372,000	413,000
	Total	113,000	372,000	485,000
300m	Primary Dredging	72,000	0	72,000
	Maintenance Dredging	0	310,000	310,000
	Total	72,000	310,000	382,000
400m	Primary Dredging	72,000	0	72,000
	Maintenance Dredging	0	248,000	248,000
	Total	72,000	248,000	320,000
500m	Primary Dredging	72,000	0	72,000
	Maintenance Dredging	0	217,000	217,000
	Total	72,000	217,000	289,000

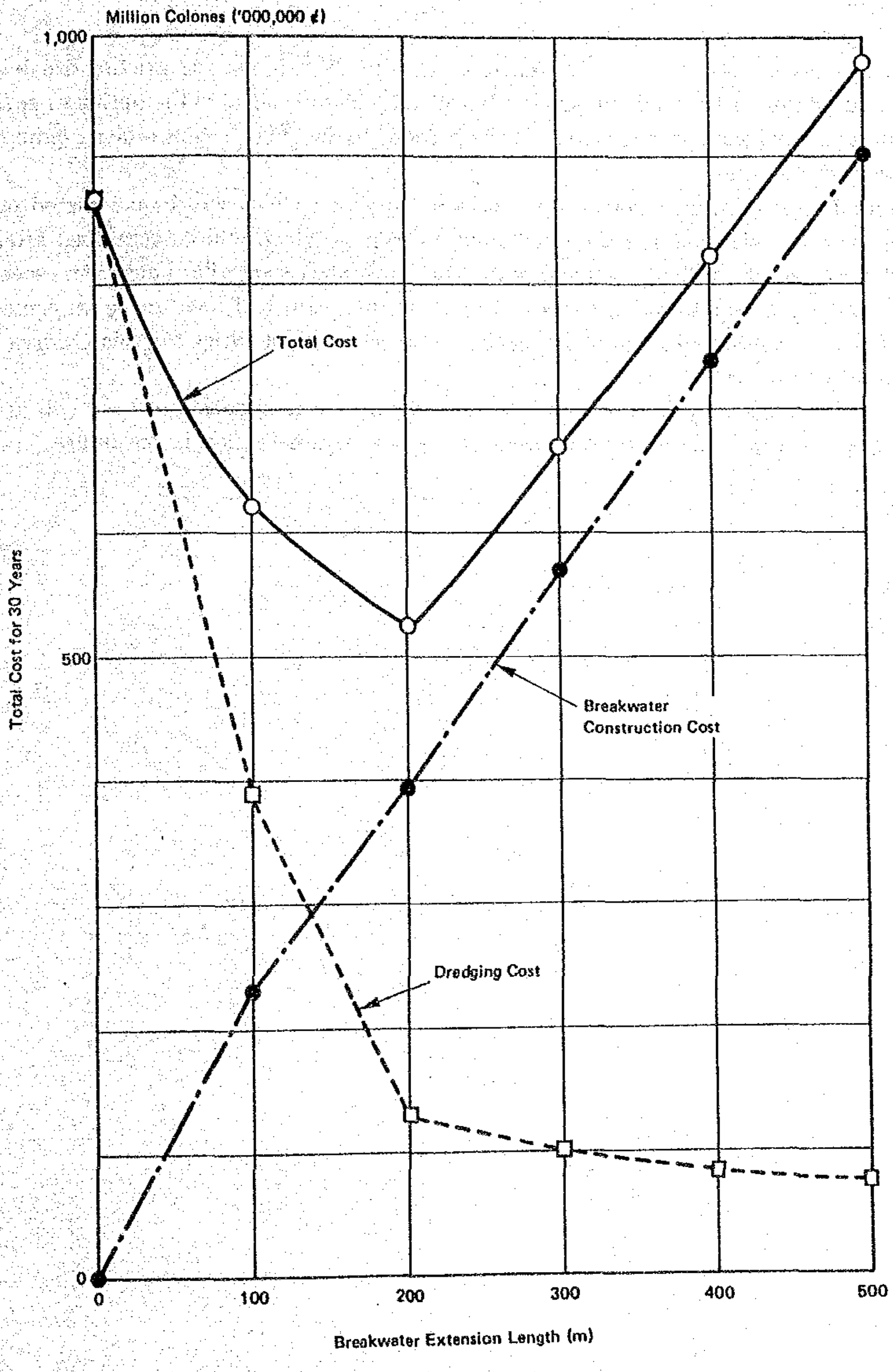


Fig. 6 Cost Comparison of Each Breakwater Length

3. Summary

A new breakwater extension of 200 m in the same direction as the existing breakwater and the dredging of unavoidable sand sediment are recommended as the optimum counter-measures against sand sedimentation in the harbour basin. Fig. 7 shows the recommended breakwater extension.

The dredging includes not only the primary dredging which will be completed by the target year, but also the periodic maintenance dredging which will be continued after the target year. As the sediment volume in the harbour area is somewhat uncertain, especially under rough sea conditions, an expedient dredging program will have to be implemented. This must be considered when planning the construction of facilities for this Caldera Port maintenance project.

Regular site surveys concerning the sand drift over a long period of time will also be necessary for a more accurate estimation of the sand sedimentation in the future.

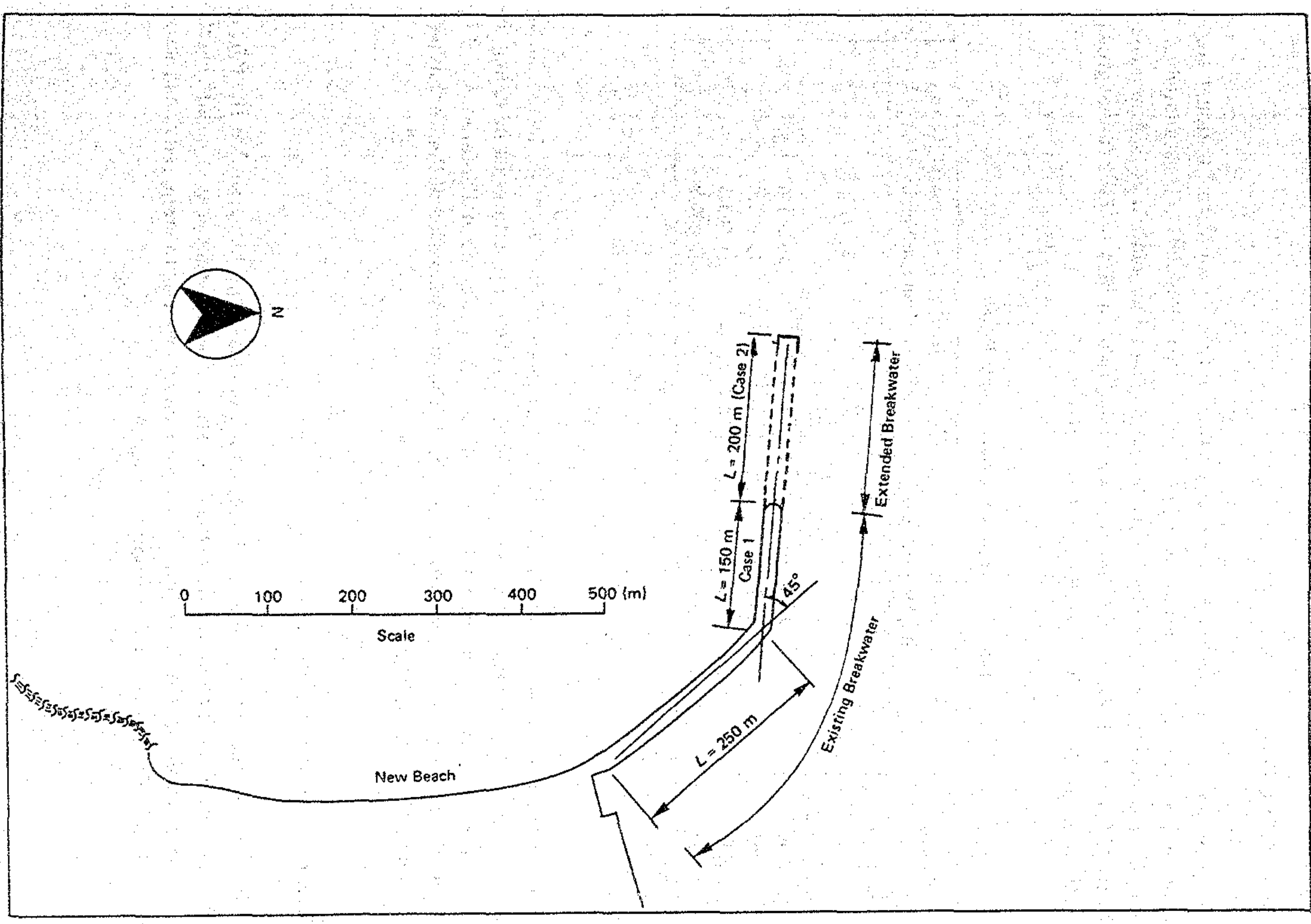


Fig. 7 Alternative Designs of the Breakwater Extension

1. Port Traffic Forecast

As prerequisites for the port traffic projection, future Costa Rican national socio-economic indices such as population and GDP are projected. Population is estimated using the annual increase rate projected by CELADE and the actual population in 1982 as studied by DGEC/MEIC. GDP is projected based on the actual GDP in 1984 and the annual growth rate estimated by BCCR. The results are shown in Table 6.

Table 6 Projected Socioeconomic Frame

Year	Population (Unit : '000 persons)	GDP at 1966 constant prices (Unit : million colones)
(Actual)		
1982	2,371.5	8,742.6
(Projected)		
1990	2,895.4	10,521.0
1992	3,027.7	11,053.6
1995	3,224.4	11,903.5
2000	3,545.0	13,467.8

The future port cargo volume at the Port of Caldera is then forecast based on the projected socioeconomic frame. The future throughput at the port is forecast including the throughput at the Port of Puntarenas because all the port functions at Puntarenas will be transferred to the Port of Caldera in the future due to the superannuation of Puntarenas pier. The results are shown in Table 7.

2. Target Year of the Project

This Maintenance Project aims at the resolution of current problems so that the Port of Caldera can accommodate all the projected port cargoes in the target year. Considering the projected cargo volume and the improved port capacity as well as the required construction period, it is appropriate to set the target year as 1992.

Table 7 Projected Cargo Volume at the Port of Caldera

	IMPORTS				EXPORTS				TOTAL			
	1984[1)]	1992	1995	2000	1984[1)]	1992	1995	2000	1984[1)]	1992	1995	2000
Grain	131,167	166,100	158,900	149,200	—	—	—	—	131,167	166,100	158,900	149,200
Automobiles	4,816	21,900	24,700	29,900	—	—	—	—	4,816	21,900	24,700	29,900
General Cargo												
Iron and Steel	53,185	83,000	90,000	103,800	—	—	—	—	53,185	8,300	90,000	103,800
Fertilizer	—	—	—	—	5,500	10,000	12,000	16,000	5,500	10,000	12,000	16,000
Others	198,157	329,000	387,000	498,000	78,668	153,300	207,400	322,100	276,825	482,300	594,400	820,100
(Containerized)	(28,452)	(120,700)	(253,800)	(432,100)	(26,760)	(41,000)	(86,700)	(184,600)	(55,212)	(161,700)	(340,500)	(616,700)
TOTAL	387,325	600,000	660,600	780,900	84,168	163,300	219,400	338,100	471,493	763,300	880,000	1,119,000

Source 1) : CUADROS ESTADISTICOS SOBRE SECTOR TRANSPORTES 1984, DGP/MOPT
Note : Cargo volume at the Port of Caldera includes that handled at the Port of Puntarenas in the past.

3. Project Strategy

The overall strategy of this Maintenance Project for the Port of Caldera can be summarized as follows :

(1) To basically resolve the sand sedimentation problem in the harbour which has decisively interfered with the expected port functions.
(2) To cope with urgent factors such as the transference of the grain import function, the rapid progress of containerization in the maritime transportation and the increase of port cargoes.
(3) To minimize costs by aiming at multipurpose use of the terminal which will handle a variety of commodities with a few existing berths.

Port facility improvement planning is studied along with the strategy. This chapter mainly studies the mooring facility improvement planning and the overall port layout.

4. Extension of the −10m Quaywall

To accept grain cargoes without any harmful influence on the port operations for other cargoes, it is necessary to improve quaywalls so that one grain vessel and one container ship can berth simultaneously at berths No. 1 and No. 2. Accordingly, the present berth length of 150 m at the No. 2 berth should be extended to the appropriate length considering the ship length of large ships.

There are three alternatives to extend the existing berth length of 150 m up to the necessary length (refer to Fig. 8).

Alternative A: to extend the berth length of the −11 m quaywall to the west
Alternative B: to construct a new pier in front of all three quaywalls
Alternative C: to deepen part of the existing −7.5 m berth up to −10 m

Alternative A is selected as the best alternative to secure the necessary berth length of −10 m quaywall. Accordingly, the existing No. 1 guaywall should be extended by 50 m. To secure the necessary berth length, it is sufficient to construct a 50 m long small pier (a gangway and mooring dolphin). However, the entrance channel to the small craft basin and an allowance for sand sedimentation should be fully considered when extending the berth.

5. Port Layout

Port facilities and equipment which require improvement in accordance with the strategy are as follows :

(1) Countermeasures against sand sedimentation
   1) Breakwater extension : 200 m long
   2) Primary dredging in the harbour : Volume of 72,000 m^3
   3) Periodic maintenance dredging : Approximately 60,000 m^3/five years
(2) Enlargement of mooring facility capacity in response to the necessity of handling grain imports and the progress of containerization in sea transportation
   1) Shift of the foot of the existing breakwater 50 m to the west : 162 m long
   2) Restoration of the −3.0 m small craft basin : 50 m × 90 m
   3) Construction of the −3.0 m quaywall : 110 m long
   4) Construction of the gangway : 45 m long
   5) Construction of the mooring dolphin : 1 dolphin
(3) Reinforcement of cargo handling capacity in response to the necessity of handling grain imports and the multipurpose use of the terminal
   1) Reinforcement of the cargo handling equipment
   2) Pavement of the open yards : Area of 42,000m^2

Incorporating the conclusions of this chapter and the results of the analyses of countermeasures against sand sedimentation and inefficient cargo handling systems, the proposed port layout in the target year is shown in Fig. 9.

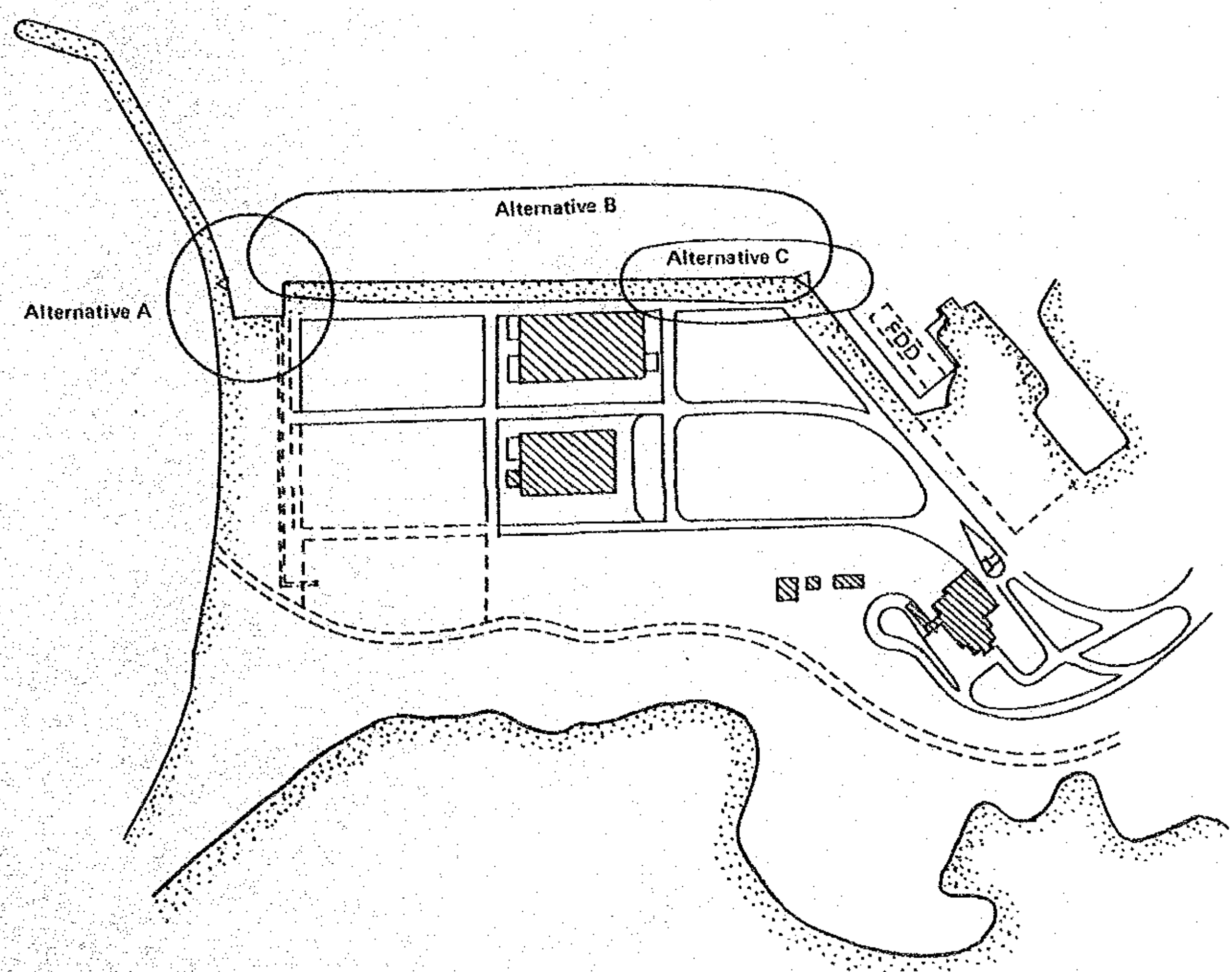


Fig. 8 Alternative Berth Extension Methods

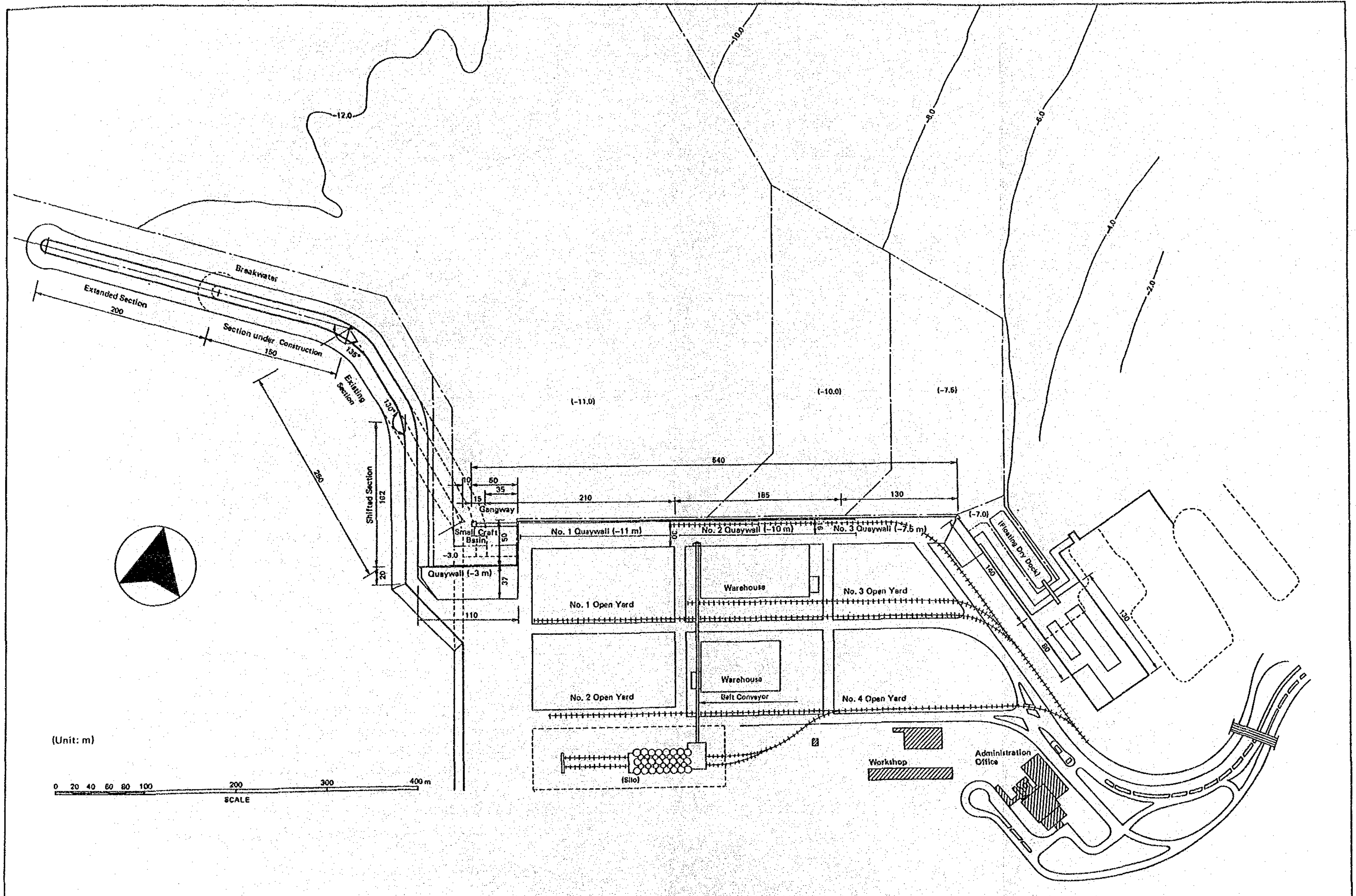


Fig. 9 Maintenance Plan of the Port of Caldera

IV IMPROVEMENT PLAN FOR PORT OPERATIONS

The study aims at the multipurpose use of the terminal which will be able to accommodate a wide variety of cargoes including general cargo, steel goods, automobiles, containers, and break bulk grain using the existing three berths. For the multipurpose use of the terminal to function efficiently, systematic management and a well-coordinated operation system will be necessary as outlined in the study.

1. Cargo Handling Improvement Plan by Main Commodity

On the average, about 40% of the total working hours for handling cargo are being wasted. Reducing this wasted time is a key point of improving port operations. Actually, it is not possible to reduce this idle time to zero, but it should be possible to reduce it. The cargo working efficiency by cargo commodity at present and in the target year of 1992 at the Port of Caldera are shown in Table 8.

Table 8 Cargo Working Efficiency

Kind of Cargo	Working Efficiency in 1985	Working Efficiency in 1992
General cargo	20 metric tons/h	24 metric tons/h
Steel goods	40 metric tons/h	48 metric tons/h
Containers*)	7 containers/h	12 containers/h
Break bulk grain	20 metric tons/h/machine	200 metric tons/h/machine

Note: *) The container working efficiency in 1992 is assumed to be 80% of that in Japan under the same conditions.

2. Break Bulk Grain Cargo Handling

Grain cargo handling will have a great impact on the other cargo handling operations. The handling of grain is a new project for the Port of Caldera, and will require a large investment. The bottleneck in the present grain cargo handling system is the time lost when railway cars are changed on the pier and when the cars travel between Puntarenas pier and the silos. To improve the efficiency, it is necessary to separate the stevedoring operation and the operation of carrying the grain to silos located outside the port area.

To separate these operation, it is necessary to construct new silos at the port with at least the same capacity as the maximum handling tonnage of one grain cargo vessel, that is 20,000 tons.

For the grain cargo handling, the four alternatives shown below are studied.

Alternative I. 2,000 tons/h pneumatic unloader and a belt converyor of the same capacity (fully mechanized system).

Alternative II. Two 200 tons/h pneumatic unloaders and a 400 ton capacity belt converyor (fully mechanized system).

Alternative III. Unloading using ship's gear and unloading grab buckets, grain cargo is then carried by a belt conveyor system.

Alternative IV. Same unloading method as Alternative III, but grain cargo is carried to the silo by dumptrucks.

As noted in the study, Alternative II is recommended.

3. Storage Improvement Plan

The two existing warehouses and four existing open yards will be sufficient to cover demand in 1992. The overall layout plan is shown in Fig. 10.

Points to be improved are as follows :

(1) Yards No.2, 3, and 4 should be paved completely.
(2) Yards No.1, No.2 and part of No.4 should be lined with container slots.
(3) Yards No.3 and No.4 should be lined with suitable area units.
Fixed numbering of each area will make it easy to manage open yard cargo storage.

4. Terminal Improvement Plan

The maximum container storage capacity in 1992 is as follows:

Loaded containers : 1040 TEU
Empty containers : 288 TEU

The container yard allotment plan is shown in Figs. 11 (a) and 11 (b).

5. Cargo Handling Machinery

Cargo handling machinery presently owned by INCOP comprises 74 units as listed in Table 9. The additional machines recommended for the Port of Caldera are listed Tables 10 (a) and 10 (b).

6. Repairing and Training

Since the Port of Caldera opened in December 1981, INCOP has been directly executing repairs and maintenance works, except for major repairs. However, as most of the machines are becoming old, INCOP will need to reinforce its maintenance ability.

The cargo handling efficiency and all of the port operations depend upon the ability and attitude of the port workers. Thus, it is important to make efforts to train port workers in a systematic way.

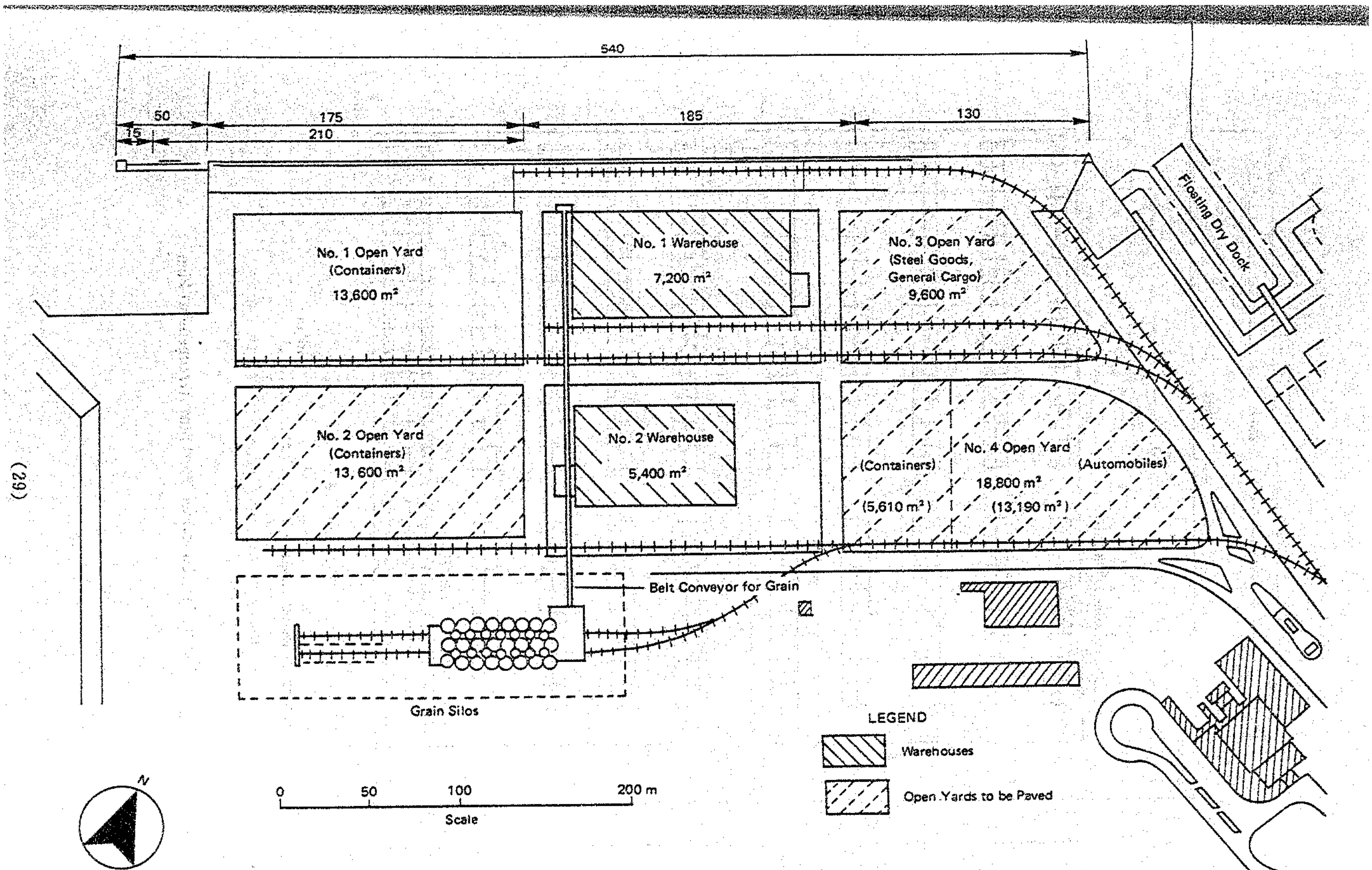


Fig. 10 Terminal Layout

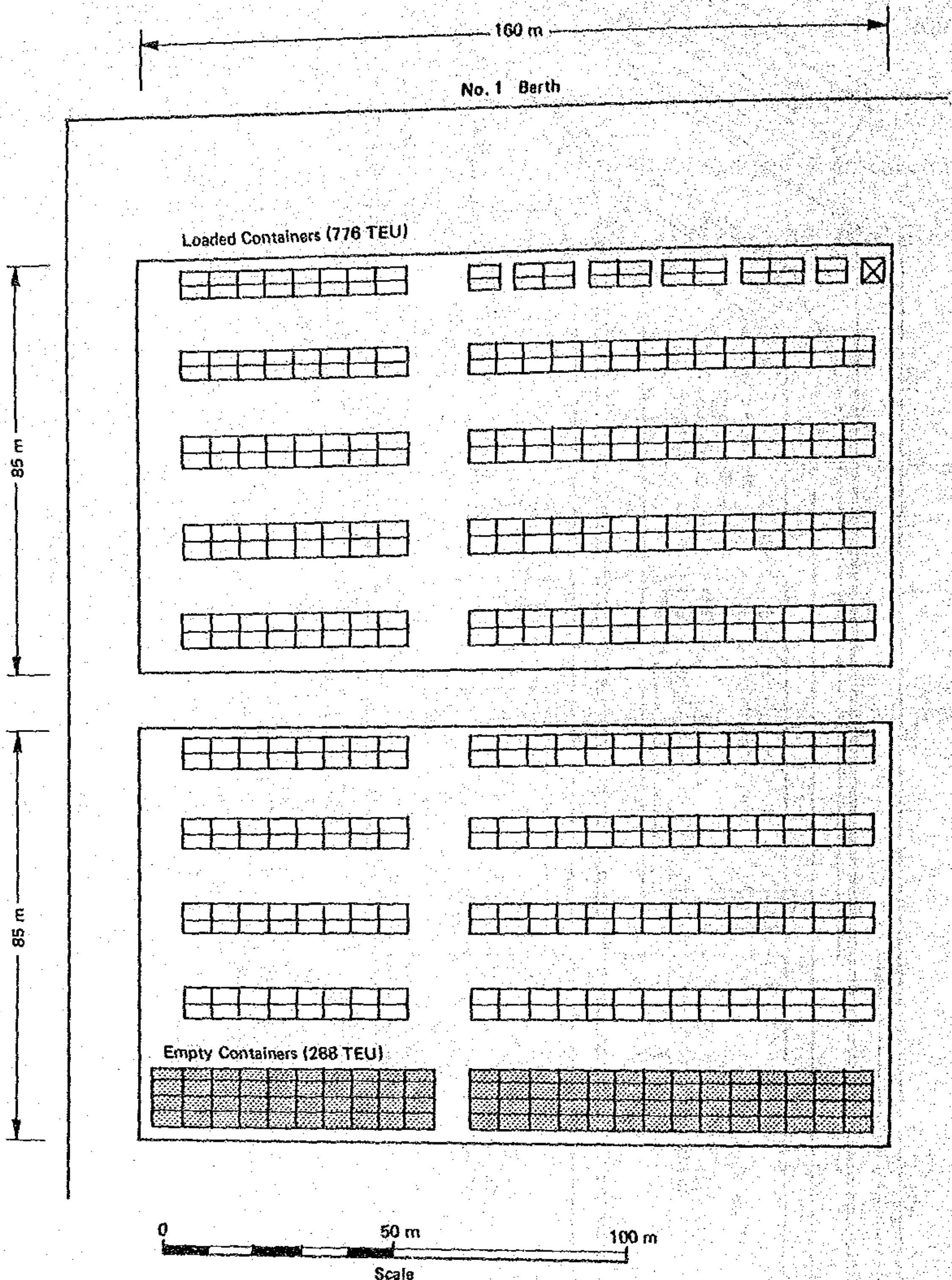


Fig. 11 (a) Container Yard Slot Arrangement Plan

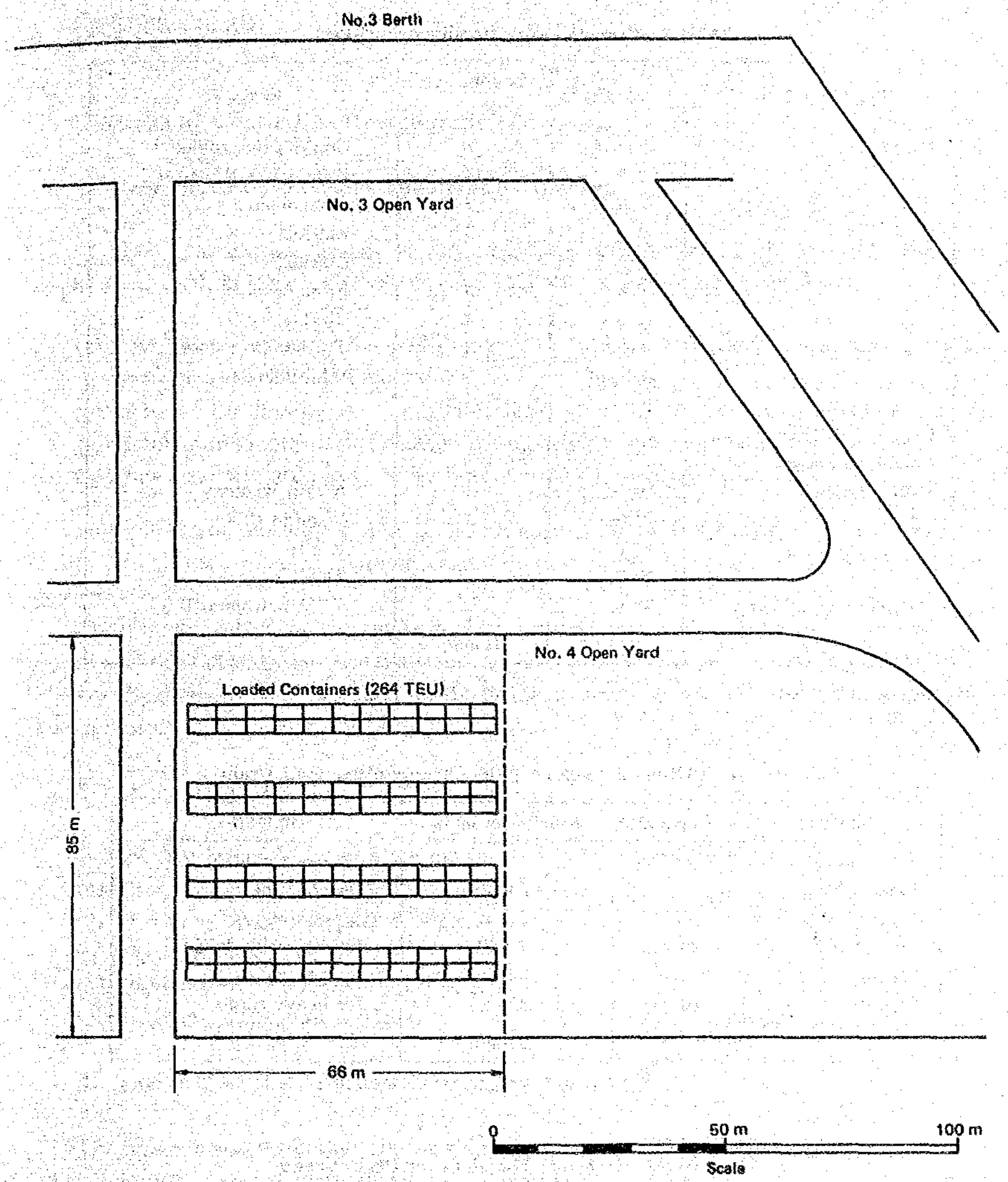


Fig. 11 (b) Container Yard Slot Arrangement Plan

Table 9 Present Cargo Handling Machines

Type of vehicle	Capacity	Number of units	Remarks
Forklift	2.0 tf	7	Clark(5), Caterpiller(2)
	2.5	14	Komatsu(10), Nissan(4)
	3.0	2	Caterpiller(2)
	3.5	3	Clark(3)
	5.0	2	Clark(2)
	6.0	3	Komatsu(3)
	10.0	1	Clark(1)
Tractor	2.5	3	TCM(3)
	680 kgf	3	John·Deere(3)
Trailer		24	
Container tractor		2	
Container chassis		4	
Mobile crane	9.0 tf	1	Austin Western
	18.0	1	Made in USA
	25.0	1	P & H
	30.0	1	TCM(1)
Container frontloader	30.0	2	TCM(1), Kalmar(1)
Total		74 units	

Table 10 (a) Additional Machinery for Cargoes other than Grain

Machine	Capacity	Number of units	Remarks
Frontloader	35 tons	1 unit	for containers
Tractor head		2 units	for containers
20'/40'chassis		3 units	for containers
Frontloader	10 tons	1 unit	for empty containers
Forklift	3 tons	10 units	for general cargo
Forklift	20 tons	2 units	for heavy cargo
		19 units	

Table 10 (b) Necessary Machines for Grain Cargo

Machine	Capacity	Number of Unit
Pneumatic Unloader	200 t/h	2
Bucket Elevator	400 t/h	1
Belt Conveyor (Movable)	400 t/h, $L=200$ m	1
Belt Conveyor (Fixed)	400 t/h, $L=250$ m	1
Small Bulldozer	2 tons	2

V DREDGING PLAN

1. Appraisal of Alternative Dredging Methods

1.1 Relation to the Primary Construction Works

The construction proposals concerning the maintenance project of the Port of Caldera put forth in CHAPTER VI~CHAPTER VIII are summarized as follows.

(1) Breakwater construction and dredging of harbour sedimentation as countermeasures against sand sedimentation
(2) Shift of the breakwater foot, and construction of a −3.0 m quaywall, mooring dolphin and gangway to enlarge the mooring facility capacity
(3) Pavement of yards in order to improve the cargo handling system

These construction works, that is the primary construction works, will be completed within 2 to 3 years, after which maintenance dredging and other maintenance works will be carried out.

Accordingly, sufficient thought must be given to the relationship between the dredging works and the primary construction works. Concretely speaking, one important point is whether the dredging fleet provided for the primary dredging and maintenance dredging can also be used for the primary construction works.

1.2 Alternative Dredging Methods

The five principal alternative methods for dredging are listed below.
(1) Dredging by cutter suction dredger
(2) Dredging by grab bucket dredger
(3) Dredging by dipper dredger
(4) Dredging by hopper suction dredger
(5) Dredging by bucket dredger

1.3 Appraisal of the Alternative Dredging Methods

The five alternative methods noted above are evaluated in light of the following criteria: soil conditions, disposal method, disposal distance, soil treatment, water depth, dredging area, meteorological and marine conditions, working period and suitability for various purposes such as the breakwater construction. If an alternative is judged to be unsatisfactory in terms of any of these criteria, then that alternative cannot be recommended as the appropriate method for the dredging.

A consolidation of the evaluation is shown in Table 11. As is clear from the table, the grab bucket method is the only suitable dredging method. Moreover, a grab dredger fleet could be practically and effectively utilized for other primary construction works.

Table 11 Evaluation of the Alternative Dredging Methods

Item	Kind of Soil	Hardness of Soil	Location of the Dumping Site	Applicability to the Other Works Construction	Dredging Area	Economy	Overall Appraisal
Conditions at the Site	Silty Sand	$N \leqq 10$	2.5miles	Necessary	Corner and the Narrow Area	—	
Cutter Suction Dredger (C)	○	○			●	4	
Grab Bucket Dredger (G)	○	○	○	○	○	1	○
Dipper Dredger (D)	○		○		●	3	
Bucket Dredger (B)			○			2	
Hopper Suction Dredger (H)	○	○	○		●	5	

Remarks : ○ Suitable. ● Somewhat suitable. 1 (Most Economical) ~ 5 (Uneconomical)

2. Execution Plan

2.1 Dredging Volume

Dredging work may be divided into primary dredging and maintenance dredging. The primary dredging is to be carried out following the completion of the 200 m breakwater extension for the purpose of removing the sediment accumulated behind the breakwater to maintain the projected basin water depth. The volume of material to be dredged is 72,000 m^3.

Maintenance dredging refers to the periodic dredging of the new sediment when will accumulate over time in the mooring basin behind the breakwater after the primary dredging is completed. As noted in CHAPTER VI, following the extension of the breakwater by 200 m, the annual volume of sand sediment will be 12,000 m^3. The first maintenance dredging will be carried out in 1991 at a dredged soil volume of 72,000 m^3. Roughly speaking, subsequent maintenance dredging will be needed once every five years thereafter, and on each occasion dredged soil volume will be 60,000 m^3.

2.2 Dredging Method

The material dredged by the grab dredger is to be transported by hopper barges and disposed of at sea. As indicated in Fig. 12, the disposal site may be suitably located in the area offshore Roca Carballo, about 2.5 miles N 50°W from the No.2 buoy.

It must be noted that using the present MOPT cutter suction dredger for future maintenance work would not be possible.

Region A in Fig. 13 shows the area to be dredged, particularly the sediment circulating around the tip of the breakwater. With respect to the sediment infiltrating to the back of the breakwater, it is particularly desirable to remove as much as possible of the sand close to the breakwater without causing damage to the breakwater itself. Accordingly, dredging of the area as shown in Fig. 14 is recommended.

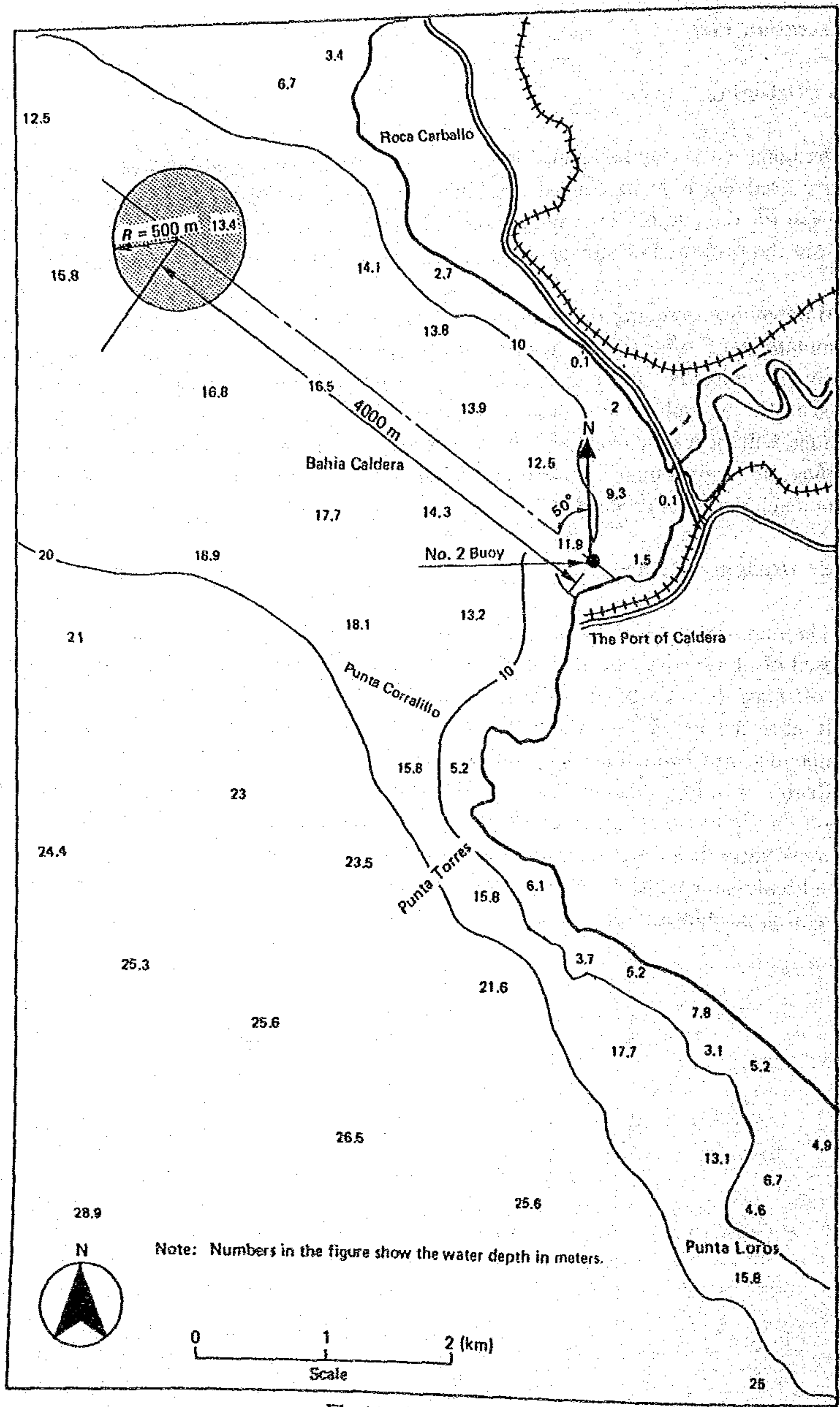


Fig. 12 Dumping Area

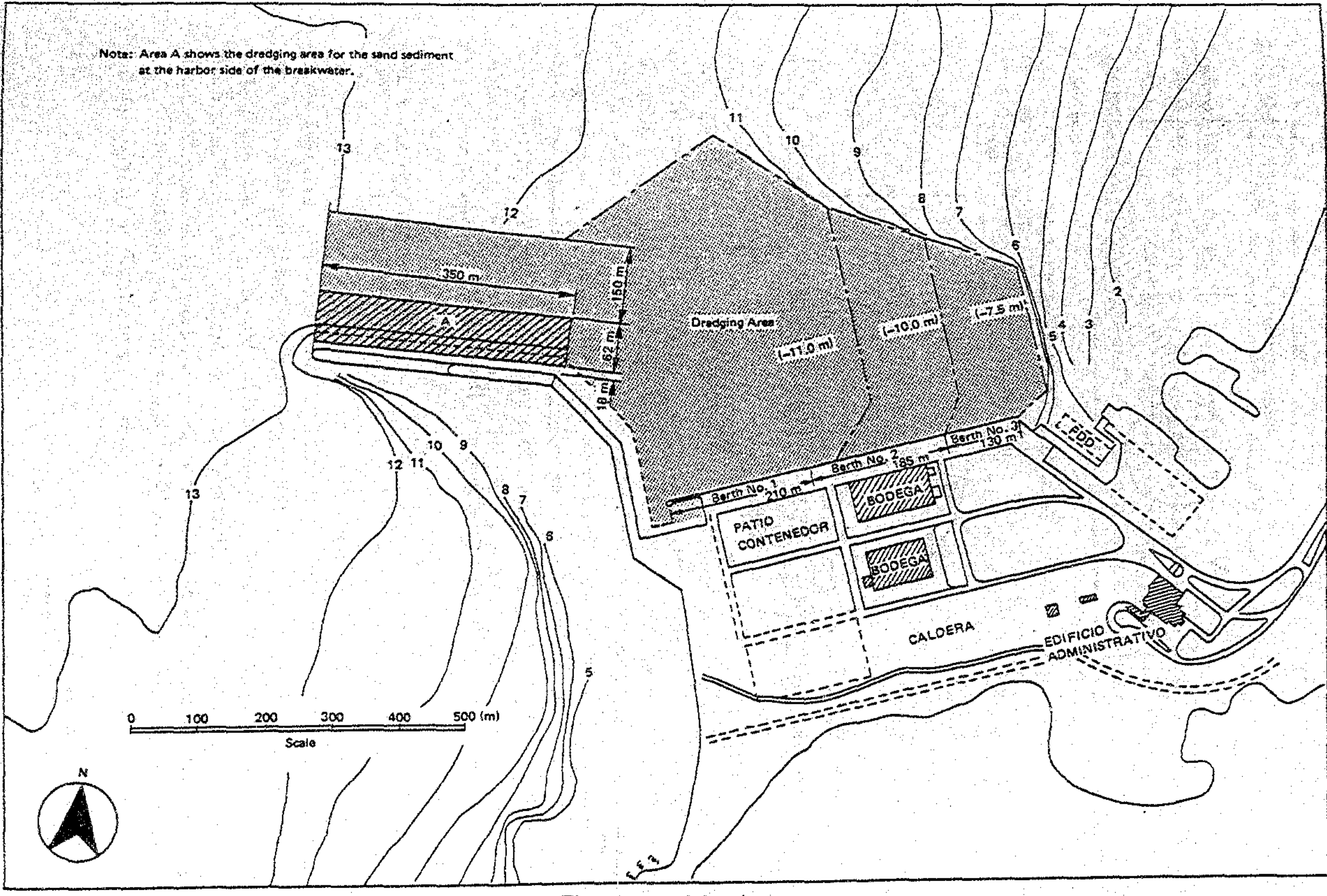


Fig. 13 Dredging Area

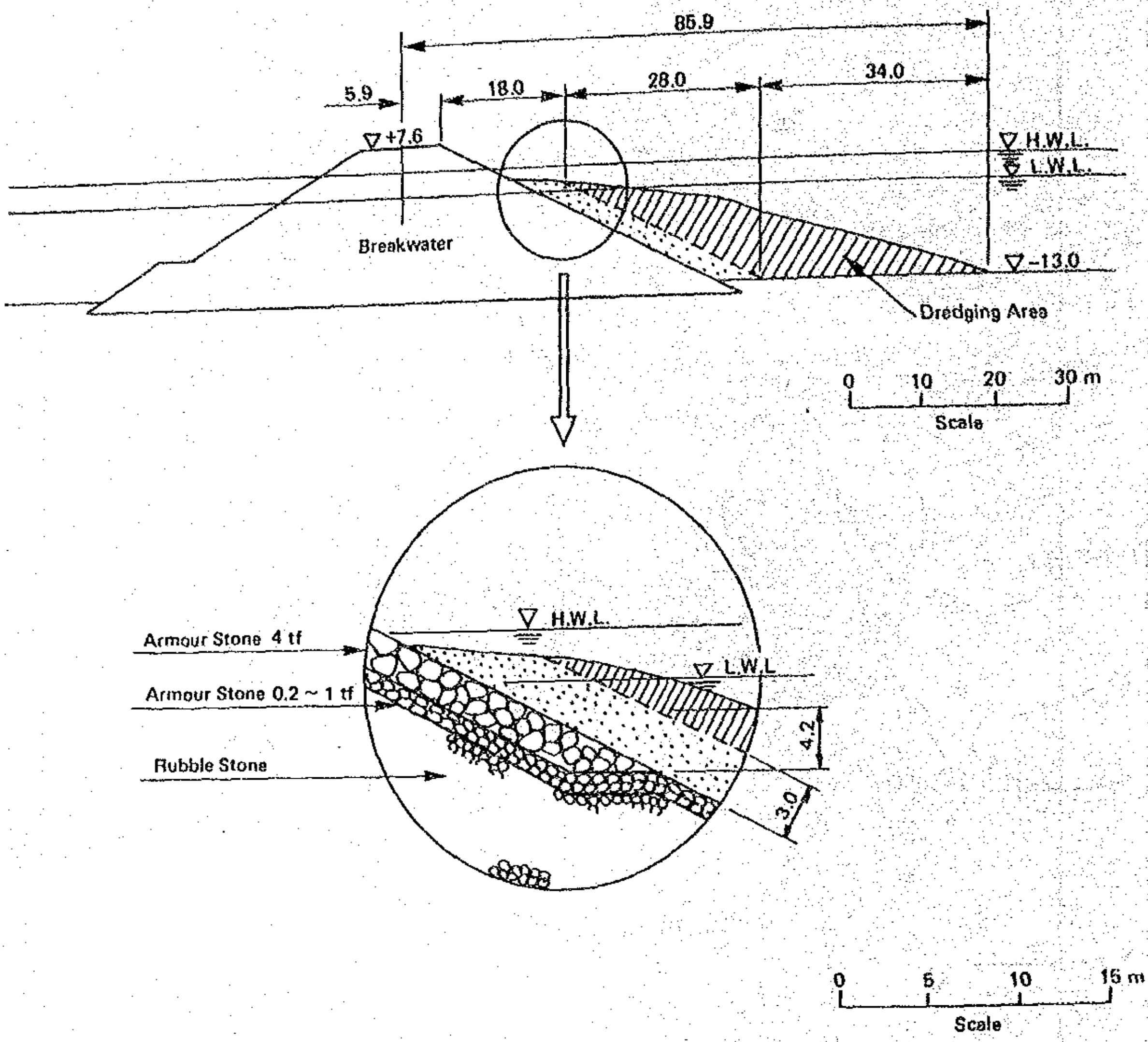


Fig. 14 Cross Section of Dredging Area A

3. Repairing the Grab Dredger Fleet and Training of Staff

3. 1 Repairing the Grab Dredger Fleet

The vessels of the grab dredger fleet are listed in Table 12.

If MOPT obtains the grab dredger fleet, regular maintenance of the fleet will be necessary to keep all of the vessels in good operating condition. The fleet will require daily maintenance, occasional repairs and annual inspection and maintenance works.

Table 12 Grab Dredger Fleet

Vessel	Quantity
Grab Dredger	1
Tugboat	1
Hopper Barge	2
Anchor Boat	1
Jolly Boat	1

In order to carry out the daily maintenance and repair work efficiently, reinforcement of the existing repair facility and up to three maintenance repair engineers will be needed.

Regular major scale inspection, maintenance, and repair of the grab dredger, tugboat, hopper barges and anchor boat must be performed in dry dock. The respective vessels function together as a fleet; hence these regular maintenance operations will have to be performed on all of the vessels at the same time.

Fortunately, construction of a ship repair yard equipped with a floating dry dock is under way within the Port of Caldera. This facility will be ideal for use as a dry dock for the regular maintenance works.

3. 2 Training System

For the maintenance dredging and other maintenance works, it is necessary for MOPT's fleet crewmembers to undergo training so that they will acquire a basic knowledge of the vessels, learn relevant skills, and become familiar with the machinery they will handle.

The training program should not only impart necessary theoretical knowledge, but it should also include practical training. Furthermore, the training team must perform actual dredging and construction works together with the trainees. Thus, experienced foreign seamen will be needed to give man to man, hands-on educational instruction over a considerable period of time at the site in Costa Rica.

VI DESIGN, CONSTRUCTION AND COST ESTIMATE

1. Designing of Structures

The structures which should be designed are as follows :

(a) As a countermeasure against sand sedimentation
- Breakwater extension of 200 m

(b) To enlarge the mooring capacity
- Shift of the existing breakwater foot
- Construction of the −3.0 m quaywall in the small craft basin
- Construction of the mooring dolphin and gangway
- Shift of the light beacon

(c) To improve the cargo handling system
- Pavement of open yards No.2, 3 and 4

The designed cross-section of the extended breakwater is shown in Fig. 15

2. Implementation Plan of the Maintenance Project

2. 1 Construction Execution Strategy

With respect to the countermeasures against sand sedimentation for the Port of Caldera specified in CHAPTER VI, the urgent extension of the breakwater, the primary dredging and the subsequent periodic maintenance dredging are all indispensable. Moreover, in order to support continued rational port activities at the port into the future, a comprehensive maintenance system for the various facilities must also be established.

The overall maintenance project at the Port of Caldera comprises the following two main parts.

(1) Construction of the various facilities and the procurement of a grab dredger fleet, construction machinery and cargo handling equipment.

(2) Subsequent regular maintenance dredging and maintenance works for the various port facilities after the target year.

The former, including the purchase of required cargo handling equipment, is hereafter referred to as the primary construction works and the latter as the maintenance works.

It would be ideal if MOPT could carry out the primary construction works itself. However, the projects are of a large scale and diverse makeup, and delays in implementing the countermeasures required to prevent sand sedimentation cannot be entertained. A consideration of MOPT's record of performance to date, as well as its present capacity to execute the various projects, indicates that the execution of primary construction works under direct MOPT management is not feasible. However, the maintenance works should be carried out directly by MOPT. Utilizing outside contractors for maintenance dredging

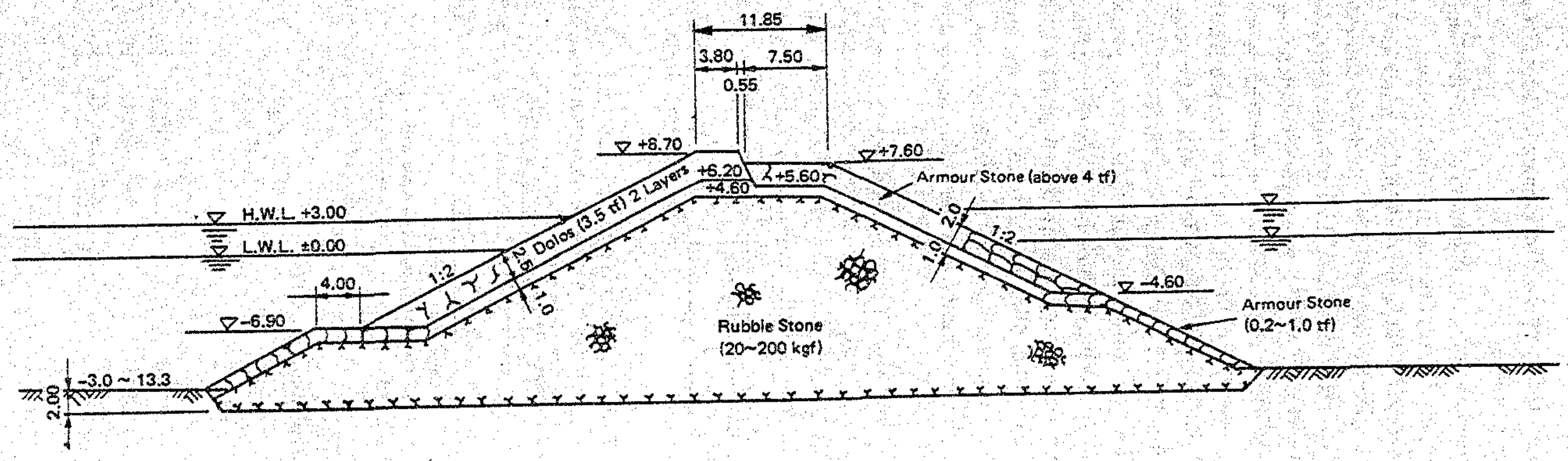


Fig. 15 Standard Cross Section of Rubble Mound Breakwater Armored by Dolos

and other maintenance works every time they are needed is uneconomical, and a timely response from contractors is not always possible.

Taking into account the above considerations, an economical and rational execution plan for the maintenance project of the port is prepared as set forth below.

MOPT will first procure the grab dredger fleet and construction machinery which are necessary to carry out the future maintenance works. Next, the fleet and equipment will be lent to the outside contractor engaged to carry out the primary construction works, and while the primary works are being carried out, MOPT employees will learn appropriate construction and dredging techniques by working together with the contractor while executing the primary works and thus acquire essential skills through on the job training.

Then, following the completion of the primary works, MOPT will make effective use of its grab dredger fleet and construction machinery for maintaining the Port of Caldera.

Only considering the primary construction works, the purchase of a grab dredger fleet and construction machinery would seem to be uneconomical. However, in the long run including the required maintenance period, these purchases are clearly justified. The vessels and tools are necessary to maintain the cargo handling capacity of the port, and, as noted above, it is not practical to have the regular maintenance works performed by a contractor. Considering the overall project, that is both the primary and the maintenance works, this is clearly the best plan.

This plan for the execution of the overall works is presented graphically in Fig. 16.

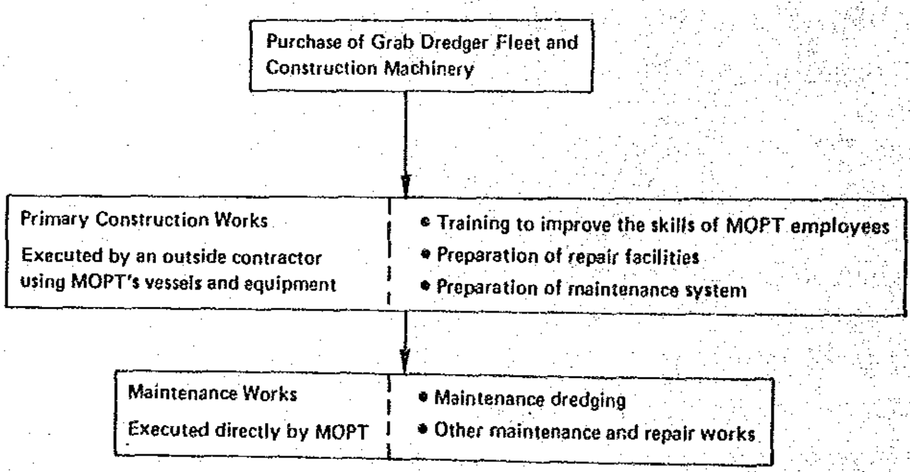


Fig. 16 Implementation Plan

2. 2 Excution Plan for Each Facility

2. 2. 1 Breakwater Extension

The extension of the breakwater is urgently needed to counter the sand sedimentation, and the extension must be completed within a short period of time to minimize the possibility that the breakwater might be damaged by rough sea conditions while under construction. Accordingly, in addition to the land-based construction carried out to date by MOPT, a combined method which includes sea-based construction work should also be considered.

The grab dredger fleet can be used for general maritime construction works by adopting various attachments, and hence it is ideal for the present project in which the breakwater extension and primary dredging are the principal primary works.

The construction work of the breakwater includes the construction of the temporary facilities such as the Dolos fabrication yard and the temporary loading pier for stones and other construction materials.

2. 2. 2 The Other Facilities

The agenda for other construction works is as follows :

(a) Shifting of the breakwater foot (including the shifting of the light beacon)
(b) Construction of a −3.0 m quaywall
(c) Construction of a mooring dolphin and gangway
(d) Construction of a repair facility for the grab dredger fleet and construction machinery
(e) Primary dredging
(f) Pavement of the yards

2. 3 Requisite Grab Dredger Fleet and Construction Machinery

The grab dredger fleet and construction machinery which should be obtained by MOPT are listed in Table 13 and Table 14.

Table 13 Grab Dredger Fleet

Vessels	Capacity	Quantity
Grab Dredger	D.E.640PS, 4.0m³	1
Hopper Barge	300m³	2
Tug Boat	D.400PS	1
Anchor Boat	D.90PS, 5 ton winch	1
Flat Barge	300 tons	1
Jolly Boat	D.100PS, 13 GT	1
Diving Boat	D.30PS, 3 ton winch	2
Survey Boat	D.40PS, 6 GT	1

Table 14 Construction Machinery

Machinery	Capacity	Quantity
Crawler Crane	80 ton	1
Crawler Crane	16 ton	2
Dump Truck	230PS, 18 ton	9
Bulldozer	141PS, D-6	3
Back Hoe	188PS, $2m^3$	1
Grader	108PS, 3.6m	1
Tyre Roller	85PS, 8～20tf	1
Wheel Loader	235PS, $3.5m^3$	1
Compressor	174PS, $17m^3/min$	1
Earth Drill	60-114mm	2
Vibrator	60 kVA	1
Trailer	320PS, 40ton	2
Generator	370PS, 300kVA	1

2. 4 Schedule of the Caldera Port Maintenance Project

The proposed schedule of the Caldera Port maintenance project is given in Fig. 17.

3. Cost Estimate

The cost estimate is presented in Table 15.

Particulars	Quantity	Unit	1987	1988	1989	1990	1991
Purchasing of Grab Dredger Fleet and Construction Machinery	1	Set	Order	6.0 Months			
Shipping of Equipment	1	Set		1.5			
Preparation of Temporary and Repair Facilities	1	Set		2.0			
Construction of the Breakwater Extension	200	m				17.4	
Primary Dredging	72,000	m³				3.0	
Shifting of the Breakwater	162 (Shifting Distance: 50 m)	m				4.5	
Construction of the Mooring Dolphin and Gangway	1	set				1.5	
Construction of the –3 m Quaywall	110	m				5.0	
Pavement of Yards	42,000	m³				1.2	
Purchasing of Cargo Handling Equipment	1	set				Order	6.0
Shipping of Cargo Handling Equipment	1	set					1.5
Education and Training of Coordinators	1	set					6.0

Remarks
═══ : Works in Foreign Countries
▬▬▬ : Works in Costa Rica

Fig. 17 Construction Schedule of the Project

Table 15 Total Cost of the Maintenance Project

(1) Project Cost

(Unit : '000 ¢)

Item	Sub Item	Cost		
		Foreign Portion	Local Portion	Total
Purchase Costs of the Grab Dredger Fleet and Construction Machinery, and Related Costs	Purchase Cost of the Grab Dredger Fleet	165,250	0	165,250
	Purchase Cost of the Construction Machinery	183,490	0	183,490
	Shipping Cost for the Grab Dredger Fleet and the Construction Machinery	73,080	0	73,080
	Construction Cost of the Repair Facilities	23,950	2,660	26,610
	Sub Total	(445,770)	(2,660)	(448,430)
Construction Cost of the Facilities to Protect the Harbour from Sand Sedimentation and Primary Dredging Cost	Construction Cost of the Breakwater Extension	181,150	116,410	297,560
	Construction Cost of the Temporary Facilities	10,890	1,070	11,960
	Primary Dredging Cost	8,270	2,390	10,660
	Sub Total	(200,310)	(119,870)	(320,180)
Construction Cost for the Enlargement of the Mooring Facility Capacity	Cost of Shifting the Breakwater	43,900	9,970	53,870
	Construction Cost of the -3m Quay Wall	19,230	31,400	50,630
	Construction Cost of the Mooring Dolphin and the Gangway	8,660	1,960	10,620
	Sub Total	(71,790)	(43,330)	(115,120)
Improvement Cost of the Cargo Handling System	Purchase Cost of the Cargo Handling Equipment for Cargoes other than Grain	64,850	0	64,850
	Purchase Cost of the Cargo Handling Equipment for Grain Cargo	192,350	0	192,350
	Purchase Cost of the Maintenance Instruments	1,640	0	1,640
	Shipping Cost for the Cargo Handling Equipment	24,090	0	24,090
	Education and Training of the Coordinators	11,770	0	11,770
	Pavement of the Yards	7,180	82,140	89,320
	Sub Total	(301,880)	(82,140)	(384,020)
Total		1,019,750	248,000	1,267,750

(2) Annual Maintenance Cost

(Unit : '000 ¢ /year)

Item	Cost		
	Foreign Portion	Local Portion	Total
Maintenance Dredging	930	300	1,230
Maintenance Works for the Facilities	1,980	5,120	7,100
Total	2,910	5,420	8,330

VII ECONOMIC ANALYSIS

1. Viewpoint of the Economic Analysis

The purpose of the economic analysis is to appraise the economic feasibility of the maintenance project for the Port of Caldera. Therefore, the analysis investigates the economic benefits as well as the economic costs which will arise from the project, and evaluates whether the net benefits exceed those which could be derived from other investment opportunities (the opportunity cost of capital) in Costa Rica.

The economic return is evaluated in terms of the economic internal rate of return (EIRR) based on cost benefit analysis using the Discount Cash Flow Method.

2. Alternative Case

In order to determine the return on the project, a cost benefit analysis is conducted. That is, the costs which will be incurred from carrying out the project are subtracted from the benefits which will be gained. To calculate the benefits of the project in economic terms, an alternative case is used. The case when an investment is made, the With Case, is compared with the case when no investment is made, the Without Case.

In this study, the following conditions are adopted as the Without Case :

(a) The breakwater is not extended.

(b) Annual dredging is carried out in order to maintain the design depth of the existing berths.

(c) Additional equipment and facilities for enlargement of cargo handling capacity are not provided.

(d) The same grain terminal is constructed as under the With Case.

3. Benefits

The following two tangible benefits, are considered in this statistical analysis :

(1) Reduction of ship staying costs

(2) Reduction of dredging costs

Investment in improved port facilities and equipment will reduce the waiting period for berth space and the period for loading and unloading cargo. The staying period of ships will be reduced, and this cost reduction is one main benefit of the project.

As mentioned in CHAPTER VI, if the existing breakwater is extended by 200 m, the sand sediment volume will be drastically reduced. The reduction of dredging costs is the other major benefit of the project. This benefit can be calculated by comparing the case where the extension of the breakwater is carried out with the case where it is not.

4. Costs

For calculation of the costs, the following prerequisites are considered :

(1) The period of economic calculation (project life) is assumed as 30 years from the beginning of the construction (i. e. from 1988 to 2017).
(2) For calculation of the construction cost of individual facilities such as the breakwater extension and the shifting the breakwater foot and also for dredging costs, the concept of monthly rental fees against the purchase costs of the grab dredger fleet and construction machinery are applied. In the calculation of the rental fees, the lives of the fleet and repair facilities are estimated as 15 years, and the lifetime of the construction machinery is estimated as 7 years.
(3) The construction cost of the grain terminal is not included in the costs because the cost remains the same under both the With and Without Cases.
(4) Dreding costs are calculated based on the dredging volume in Fig. VI—26 (a).
(5) The life of the cargo handling equipment except for maintenance tools is estimated as 10 years, and the life of maintenance tools is estimated as 15 years.
(6) Maintenance costs for each piece of equipment and for each facility are considered.
(7) The salvage values of the cargo handling equipment and the maintenance tools in the With Case and the salvage value of the grab dredger fleet in the Without Case are considered in 2017.

5. Economic Profitability

The EIRR of the project is calculated to be 23.7%.

There are various views concerning the evaluation of the EIRR to guide the judgement as to whether a project is feasible or not. The leading view is that the project is feasible if the EIRR exceeds the local opportunity cost of capital.

In port investment projects, EIRRs usuall range from 10% to 20%. It is generally considered that a project with an EIRR of more than around 10% is economically feasible. In this case, only taking into consideration the two items which are easily quantified, the EIRR of the project is 23.7%. Therefore, the project is considered to be feasible.

6. Sensitivity Analysis

Sensitivity analysis is made for three cases as follows :

(1) Case EA : The construction costs other than the costs of dredging and the purchase costs of the dredging fleet, construction machinery and cargo handling equipment increase by 10%.
(2) Case EB : The forecast port cargo volume decreases by 10%.
(3) Case EC : The ship costs decrease by 29%.

The calculation results of the sensitivity analysis prove that each case would be feasible.

7. Conclusion

From the viewpoint of the economic analysis, that is the benefit of the nation, this project can be regarded as feasible.

VIII FINANCIAL ANALYSIS

1. Viewpoint of the Financial Analysis

The purpose of the financial analysis is to ascertain the financial viability of the project itself. The investment effects of this project are analysed based on the financial internal rate of return (FIRR) using the Discount Cash Flow Method.

The objects of this financial analysis are limited to the revenues and costs related to this project. The revenues which will be considered as arising from this project are the port tariffs on the incremental cargo volume except for grain cargo, i. e. on the cargo volume difference between the Without Case in 1991 and the With Case in 1992, and all the port tariffs which will be collected from the handling of grain cargo. Costs considered in this study are limited to the construction costs for enlargement of the cargo handling capacity as listed below.

(a) Shift of the foot of the existing breakwater
(b) Construction of the −3.0 m quaywall
(c) Construction of the mooring dolphin and gangway
(d) Pavement of the open yards
(e) Purchase of additional cargo handling equipment
(f) Purchase of grain cargo handling equipment

2. FIRR

The FIRR of the project is calculated as 8.26%.

The desirable level of FIRR varies depending on the time and place and the expectations of the lender and borrower. For borrowers, the average interest rate paid on borrowed funds is the lower limit. In this project, 76.3% of the overall construction cost is the foreign portion, and it is assumed to be raised through soft loans with a 4.75% interest rate. Therefore, the FIRR is required to exceed 3.62%, which is the weighted average interest rate for all the project funds. Judging from this point of view, this project can be regarded as feasible, since the FIRR of 8.26% is well above the weighted average interest rate.

3. Sensitivity Analysis

Sensitivity analysis is made for three cases as follows :

(1) The port tariff revenues decrease by 10% (Case FA)
(2) The construction costs increase by 10% (Case FB)
(3) The revenues decrease by 10% and the costs increase by 10% simultaneously (Case FC)

The FIRR is calculated for each of the 3 simulation cases. The calculations show that every FIRR exceeds the lower limit of 3.62%. The results of the sensitivity analysis thus prove that each case would be feasible.

4. Conclusion

From the viewpoint of the financial analysis, that is the profitability of the project itself, this project can be regarded as feasible.