CHAPTER III PRESENT SITUATION AT THE TWO PORTS

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III-1 Role among Chilean Ports

(1) Situation of the Two Ports

The JICA study team went on investigation tours through Chile to clarify the functions of the major ports (refer to Fig. III-1-1), and the results of the comparative analysis are shown in Table III-1-1. All the ports in Chile have their own specialized functions, and that there are no redundancies, at least at present.

The ports of northern Chile are almost exclusively export ports for minerals, fish pellets and so on. On the other hand, the southern ports are primarily domestic public ports for forestry products, wood pulp and fish. The two study ports are for public use and especially for import of industrial goods such as a electronic products, clothing, chemicals and other daily necessities including foods. The activities of the two ports are thus closely connected to the living standard of the Chilean people, and the development of the two ports may be one of the most affective ways to improve this living standard and to increase the national income. The development of the ports will, in and of itself, directly benefit the Chilean economy through strengthening the competitive power of Chilean exports on the world market.

Of these major ports, the two study ports, Valparaiso and San Antonio, function as the gateway of the Santiago Metropolitan area which is their hinterland, and therefore the activities of these ports significantly affect the national economy.

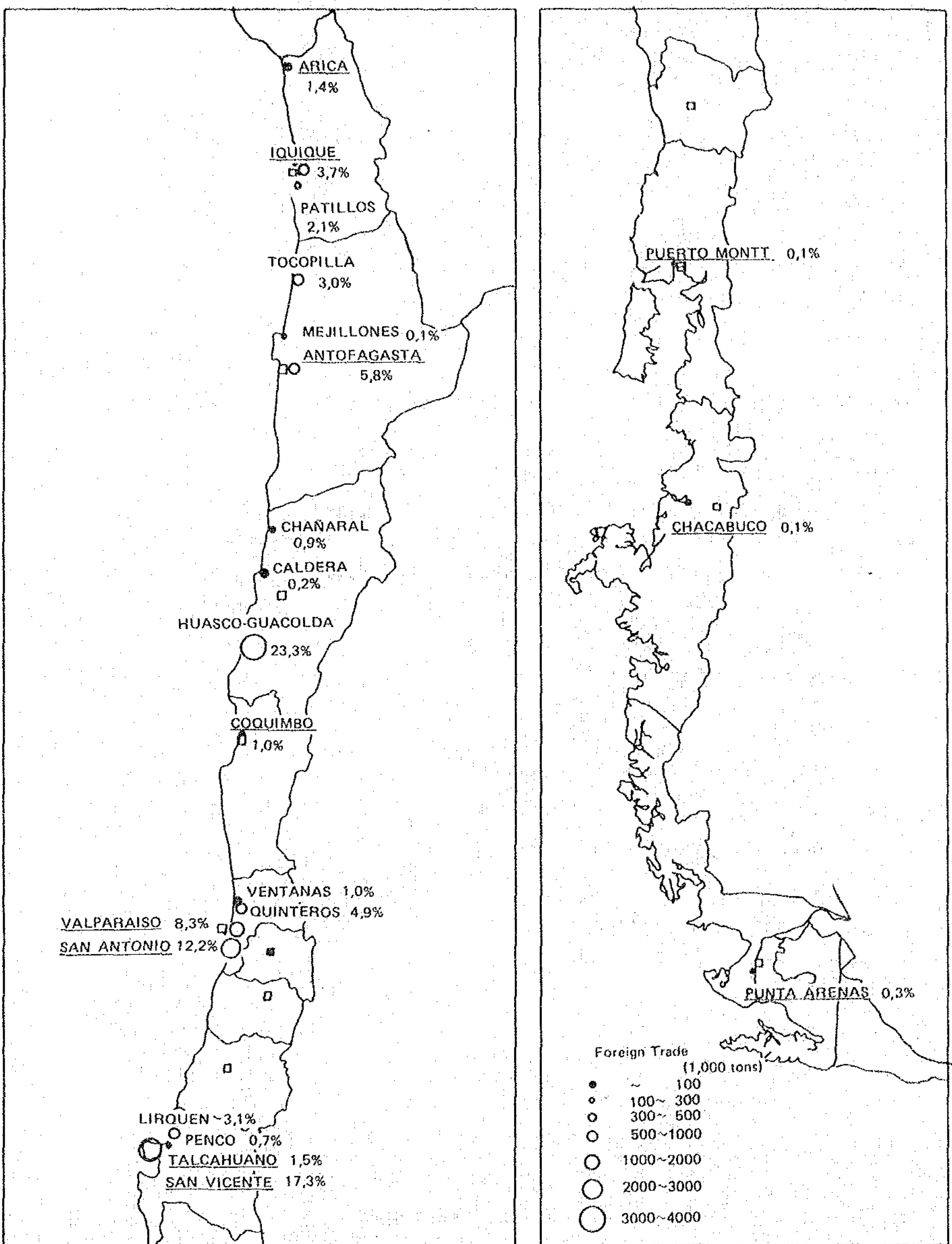


Fig. III-1-1 (1) Distribution of Major Ports in Chile (Foreign Trade)

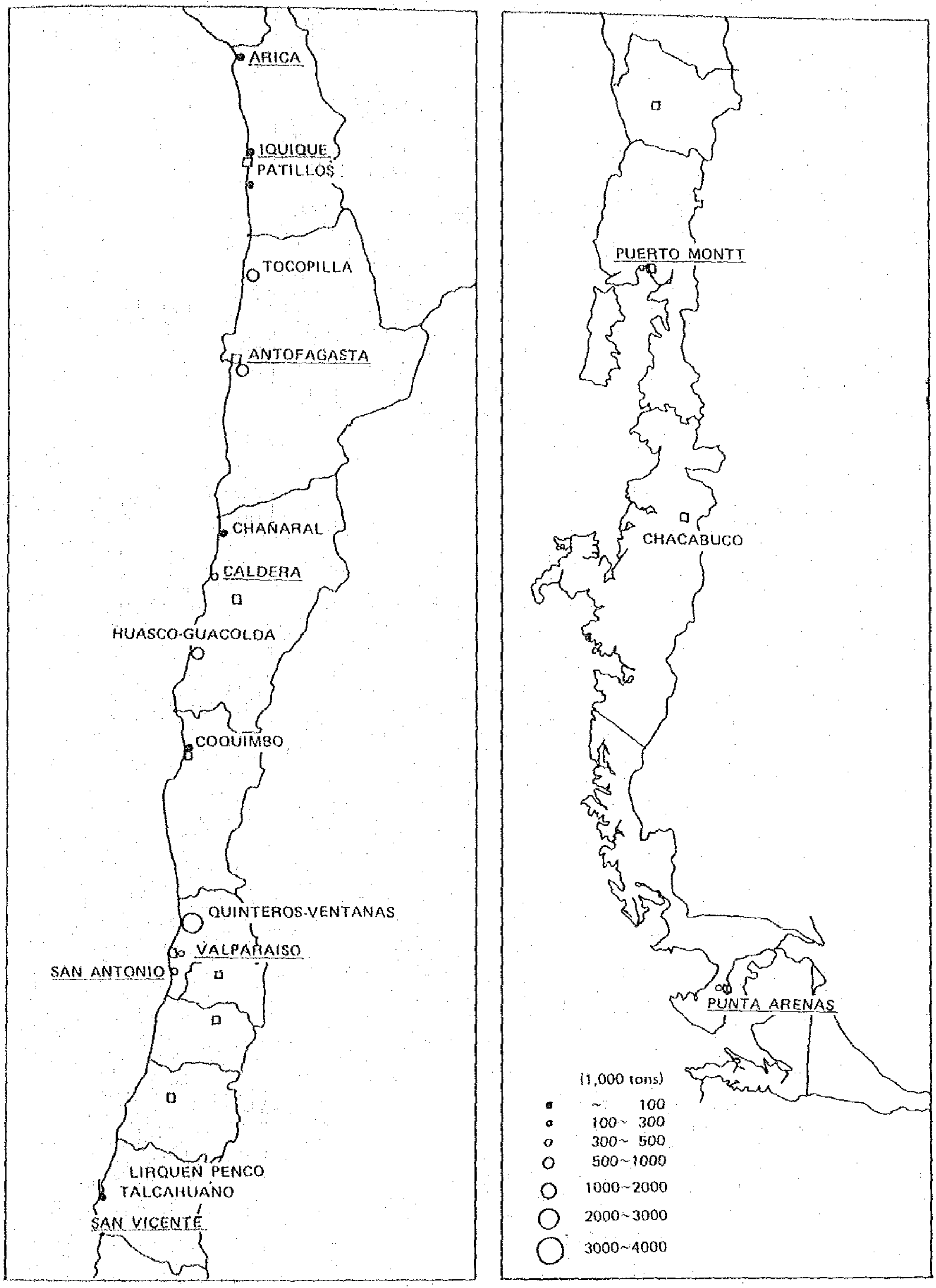


Fig. III-1-1 (2) Distribution of Major Ports in Chile (Domestic)

Table III-1-1 Functions of Major Ports in Chile (preliminary results of investigation)

No.1

Name of Port	Location and Access	Main Facilities	Cargo	Functions	Administrator	Comments
Arica	Region I Road (Route 5) Railway (for Bolivia)	° 6 berths (-4 ~ -10.5 m) Total length 1,024 m ° 4 transit sheds (12,800 m^2) ° 6 cranes	° Cargo Volume 318,486 tons (Foreign 98%) (Domestic 2%) ° Main Commodities Fish pellets (58%) Transit to/from Bolivia 93,929 tons	Commercial and Fishery Port Transit to/from Bolivia and Peru	EMPORCHI (from 1980)	° Port facilities have excess capacity for domestic port hinterland ° It is necessary to promote/develop transit cargo to/from both Bolivia and Peru. ° Port facilities are maintained sufficiently ° It will be necessary in the future to separate bulk cargo.
Iquique	Region I Road (Route 16: connect to Route 5) Railway (connect with FF.CC)	° Berths (-10 - -12m) Total length 1,144 m ° 2 transit sheds (9,680 m^2)	° Cargo Volume 641,000 tons (Foreign 98%) ° Main commodities Fish Pellets (53%) Fish Oil (11%) Container 60,000 tons (9%)	Commercial and Industrial Fishery Port Transit to/from Argentina	EMPORCHI (Fishery port is CORFO)	° Overcapacity ° It is necessary to promote/develop transit cargo to/from Argentina ° Cargo volume handled for the industries near the port should be identified in port statistics.

No.2

Name of Port	Location	Main Facilities	Cargo	Functions	Administrator	Comments
Antofa-gasta	Region II Road (Route 5) Railway (connect with FF.CC)	° 7 berths (-9 ~ -10m) Total length 1,270m ° Fishery berth -7 m, 205 m ° 4 transit sheds (18,100 m^2) °Open strage yard (63,800 m^2) ° 14 cranes	° Cargo Volume 1,685,000 tons (Foreign 74%) (Domestic 26%) ° Main Commod-ities Copper (30%) Minerals (15%) Transit to/from Bolivia (20%)	Commercial and Fishery Port Transit to/from Bolivia	EMPORCHI	° Berths No.6 and 7 are deformed. It is necessary to carry out detailed investigation and restoration works. ° Port facilities are fully used in this port, especially the storage yard.
Talca-huano	Region VIII Road (Route 154, 148) connect to route 5) Railway (connect with FF.CC.)	° 2 berths (-6.7 ~ -7.3m) Total length 360 m ° 1 Transit shed (3,330 m^2) ° 2 Cranes	° Cargo Volume (1983) 335,900 tons (Foreign 57%) (Domestic 43%) ° Main Commod-ities Wood, cellulose (37%) Fish meal (23%) Coal (18%)	Commercial Port	EMPORCHI	° The only available berth is the one from 1980. ° Port activity is decreasing.

Name of Port	Location	Main Facilities	Cargo	Functions	Administrator	Comments
San Vi-cente	Region VIII Road (Route 154,148: connect to Route 5) Railway (connect with FF.CC.)	° 2 berths (-10--11m) Total length 443 m ° 3 transit sheds (20,220 m^2) ° 2 cranes	° Cargo Volume (1983) 1,478,900 tons (Foreign 97%) (Domestic 3%) ° Main Commod-ities Wood (72%) Cellulose and pulp (15%)	Commercial (Wood export) Port	EMPORCHI	° Calmness is not so good. ° EMPORCHI has a port development plan (ex-pansion to 9 berths). ° It seems necessary to promote foreign commerce because of the potential of Region VIII.
Lirquen	Region VIII Road (Route 150, 148: connect to Route 5) Railway (connect with FF.CC.)	° 4 berths (-8 - -12.3 m) Total length 790 m ° Warehouse (27.000 m^2) ° Open Storage Yard (50.000 m^2)	° Cargo Volume 531.800 tons ° Main Commod-ities Wood Cellulose	Private Commercial Port	PUERTO DE LIR-QUEN S.A. (private)	° Per gang cargo handling volume is very high: 400 tons/gang-hour. ° Access road is narrow.

No.4

Name of Port	Location	Main Facilities	Cargo	Functions	Administrator	Comments
Puerto Montt	Region X Road (Route 5) Railway (connect with FF.CC.)	° 2 berths (-7.5 - -8 m) Total length 381 m ° Ferry Wharf ° 2 transit sheds (7,500 m^2) ° 4 cranes	° Cargo Volume 128.000 tons (Domestic 100%) ° Main Commod-ities Bulk cargo (84%) (Coal, Salt) General cargo (16%)	Domestic Commercial and Ferry Port	EMPORCHI	° Canal and basin are narrow. ° Improvement/development as a base port of domestic shipping is expected.
Puerto Natales	Region XII Road (Route 9)	° RO-RO Facility (-6 m)	° Cargo Volume 58.900 tons (Domestic) ° Main Commod-ities General Cargo	Domestic Commercial Port	EMPORCHI	° Ship Service (once/8 days)
Punta Arenas	Region XII Road (Route 9)	° 6 berths (-4 ~ -10.3 m) Total length 746 m (Pier type) ° 4 warehouses (4.410 m^2) ° 2 cranes	° Cargo Volume 247.100 tons Foreign (29%) Domestic (71%) ° Main Commod-ities Industrial prod-ucts (17%) Food (14%)	Domestic Commercial Port	EMPORCHI	° Apron is narrow. ° North part of the pier is used by Navy. ° Cargo cannot be handled when winds are strong. ° Significant waves enter the port area.

No.5

Name of Port	Location	Main Facilities	Cargo	Functions	Administrator	Comments
Terminal of ENAP	Region XII	° Dolphin berth (-14 m)	° Cargo Volume about 24 thousand tons ° Main Commodities Gasoline, Propane gas, Butane	Oil Terminal	ENAP (private)	° Limited time for berthing (Velocity of tidal current is 3 knots)

(*) Except the ports of Valparaíso and San Antonio

(2) Comparison of the Two Ports

The present conditions at the two subject ports can be examined through a comparison of the ports with each other. This comparison also helps in determining which roles should be played by each of the ports in the future.

1) Potential of the Immediate Hinterlands

The immediate hinterland of the port of Valparaiso including the cities of Valparaiso, Vina del Mar and Con Con has a population of about 540 thousand. The population of the immediate hinterland of the port of San Antonio, that is the city of San Antonio, is about 60 thousand. Thus, the population around the port of Valparaiso is about 9 times the population around the port of San Antonio.

Accordingly, the concentration of commercial activities around Valparaiso is also much greater. There are many tertiary enterprises in the area such as banks, service agents, stores and hotels, and, near the port, companies concerned with port activities.

According to interviews with shipping company representatives, Valparaiso is much more attractive than San Antonio as an operations base. This is probably due to the relatively advanced concentration of commercial activities at Valparaiso.

However, the port of San Antonio may be preferable in terms of the availability and the price of land.

2) Inland Transportation

Road traffic is more congested around the port of Valparaiso than around the port of San Antonio. Plans to improve the road infrastructure of the area are becoming more concrete, and include a new bypass to the port of San Antonio. The construction work on portions of this bypass have already begun.

As for the existing roads which connect the ports with the Santiago metropolitan area, there are two tunnels along the road from Valparaiso. The Valparaiso road is somewhat longer than the San Antonio road.

Both ports have railway connections with Santiago. The San Antonio line is used exclusively for cargo. The San Antonio line is about half as long as the line connecting Valparaiso with the capital.

In general, the road and rail infrastructures are better at San Antonio than at Valparaiso.

3) Features of the Two Ports

The Port of Valparaiso has wider sea areas sheltered by breakwater than the Port of San Antonio, and so the availability of entrance channels and waiting areas in the former is higher than in the latter. As Valparaiso is open to the north direction, the south and southwest winds, which are predominant in the region, do not disturb the calmness of the port. San Antonio is open to the west, and therefore the calmness of the water areas and the maneuverability of vessels suffer from the strong winds.

As for the water areas, both ports are too deep to construct such facilities as breakwaters, quays and seawalls from the viewpoint of cost efficiency, even if the average size of calling vessels becomes larger and a deeper port becomes necessary. This is especially true at the Port of Valparaiso where the high price of land is also a factor.

The space for future port development is severely limited at Valparaiso.

4) Special Activities at the Ports

The Chilean Navy maintains a base at the Port of Valparaiso, and many important military facilities are located not only on land but also in sea areas. At present, coastal navigation control is executed by the Navy insofar as it is convenient and necessary for transit vessels. However, in the future, it will be preferable to clearly separate the port into general use and military use areas.

Similar considerations should be applied to the Port of San Antonio where fishery is very active.

Due to its long history, the Port of Valparaiso has various attractive tourist points around it including a little park facing the sea, seafood resturants, souvenir shops and many monuments. Historic ports throughout the world have nice places for sightseeing, and continuously make efforts to develop these resources. In this sense, the Port of Valparaiso should be promoted for regional tourism, taking into account the neighbouring resort, Vina Del Mar. The Port of San Antonio should develop similar resources along with the overall port development.

III-2 Usage of Port Facilities

(1) Port of Valparaiso

1) Outline

(i) Port Facilities

i) Harbor and Berthing Facilities

There are ten berths owned by EMPORCHI in the port, and the dimensions of each berth and the facilities associated with each berth are shown in Table III-2-1.

The berths from No.1 to No.8 are protected by the roughly 1,000 m breakwater, but Baron pier which has 2 berths, No.9 and No.10, faces the open sea without any breakwater. The total length of the berths is 2,005 m, and their water depths are from -7.5 m to -11.0 m except for the No.10 - 5.0 m berth. As for the storage spaces in the port area, there are 14 sheds and warehouses with about 115 thousand square meters of floor space in total, and open storage yards with about 70 thousand square meters of space.

ii) Handling Facilities and Equipment

The specifications of wharf cranes are tabulated in Table III-2-2. Other equipment owned by EMPORCHI is listed in Table III-2-3; these are items which were not damaged at all by the earthquake on 3/3//85. At present, privatization of cargo handling is progressing, and the private sector owns a lot of equipment including a forklift (TAYLOR, USA) with 85,000 lbs capacity owned by AGUNSA. Utilities generally considered at wharves are electricity, water, water to vessels, lighting, communication systems and fire fighting. The present condition of the utilities provided at each berth are shown in Table III-2-4. It can be seen that most of utilities have not been damaged by the earthquake except for the fire-fighting system.

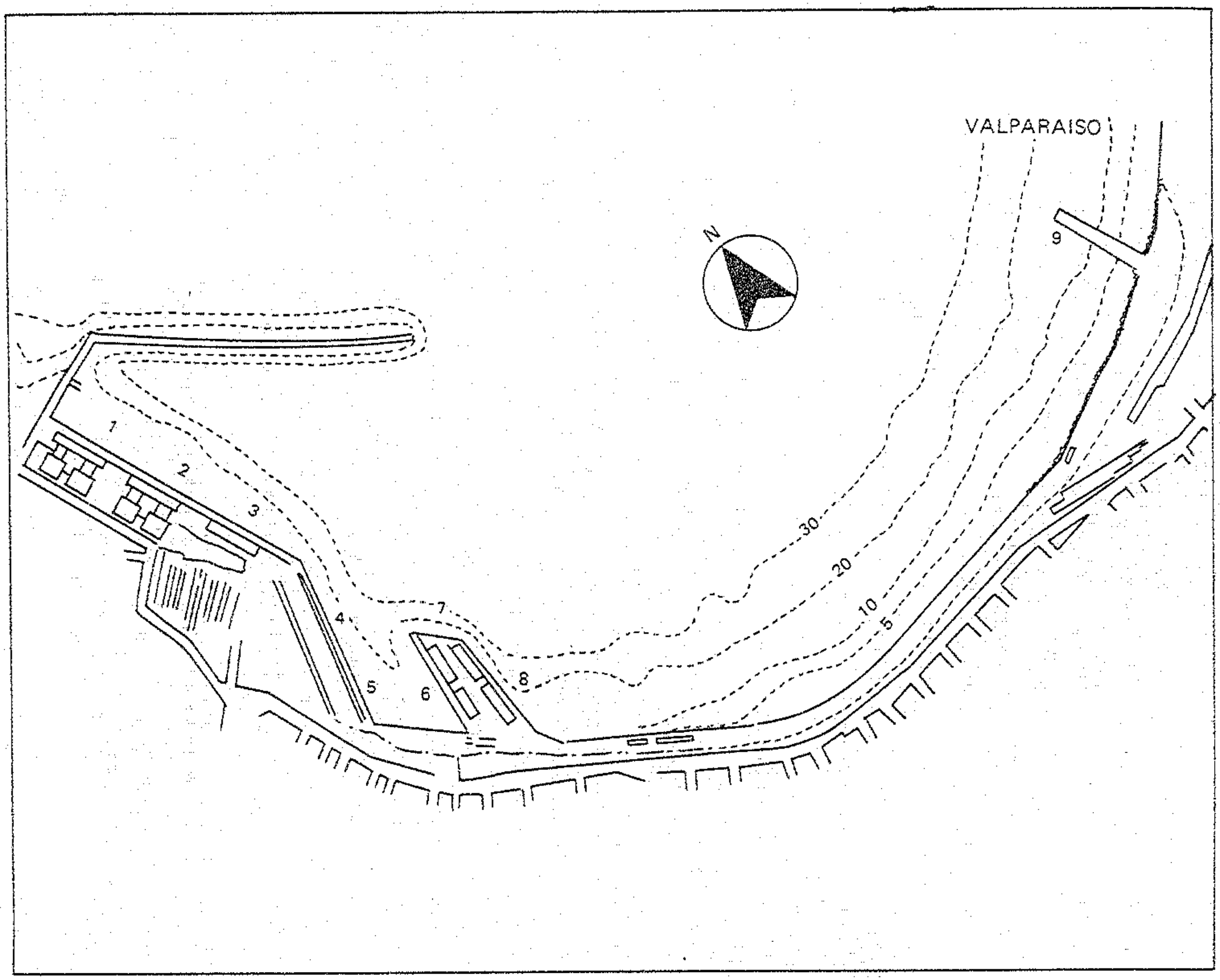


Fig. III-2-1 Plan of the Port of Valparaiso

Table III-2-1 Port Facilities (Port of Valparaiso)

Berth	1	2	3	4	5	6	7	8	9	10	Total
Length (m)	175	175	260	200	165	245	120	240	220	205	2,005
Water Depth (m)	-10.0	-10.0	-11.0	-10.0	-10.0	-9.0	-7.5	-9.0	-10.0	-5.1	
Width of Apron (m)	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	15	10	
Number of Cranes	4	4	5	-	-	5	2	6	4	-	30
Sheds and Warehouses	3 ($28,100m^2$)	3 ($28,100m^2$)	2 ($22,355m^2$)	2 ($17,318m^2$)	-	2 ($8,500m^2$)	-	2 ($10,000m^2$)	-	-	14 ($114,373m^2$)
Open Storage	3,133	3,480	6,270	16,480	8,325	-	1,000	-	-	-	38,688 (69,578)*
Year of Completion	1922-1932	1922-1932	1922-1932	1922-1932	1922-1932	1922-1932	1922-1932	1922-1932	1915-1920	1915-1920	
Type of Structure	Concrete block gravity wall	ditto	ditto	Open type with concrete piers connected at the top to concrete block wall	Concrete block gravity wall	ditto	Concrete caisson gravity wall	Concrete block gravity wall	Open type pier of reinforced concrete	ditto	
Present Water Depth at Copeline	8.5	8.1	9.4	9.0	7.5	8.5	7.5	8.0	10.0	9.0	
Height of Copeline	+4.91	+4.91	+4.91	+4.91	+4.91	+4.91	+4.91	+4.91	+6.04	+6.04	

* includes COSTANERA and PATIO

Table III-2-2 The Specifications of Wharf Cranes

Items \ Type of Crane	A Semi-portal Double-Link	B Portal Double-Link	C Semi-portal Rope Balance	C' Portal Rope Balance	D Semi-portal Rope Balance	E Semi-portal Rope Balance	F Portal Double Link
Number (31) Before Earthquake	4	4	6	0	12	4	1
Number (26) After Earthquake	4	0	4	2	11	4	1
Manufacturer (Country)	ARDELT (Germany)	ANSALDO (Italy)	MAN (Germany)	MAN (Germany)	MAN (Germany)	MAN (Germany)	HITACHI (Japan)
Year of Construction/operation	1953 (op)	1960 (con) 1961 (Op)	1966 (Op)	1985 - 6	1972 (Op)	1972 (Op)	1984 (Op)
Design Condition	Wind 50 kt	Wind 50 kt	Wind 50 kt	Wind 50 kt	Wind 50 kt	Wind 50 kt	Earthquake 0.2
Rated Load (t)	10	5.5	5	5	3	5	30.5/36
Outreach (m)	14.5	13.85	15.375	15.375	19.375	19.375	34.4
Radius (Max./Min.)	18/7	21.5/7	18/7	18/7	22/7	22/7	41/11.2
Rail Gauge (Height Difference)(m)	12.25 (6.125)	10.15	12.25 (6.125)	10.165	12.25 (6.125)	12.25 (6.125)	17
Lift Range (Above/Below Rail) (m)	23/15	23/15	23/15	23/15	23/15	23/15	24/15.5
Wheel Load (Rail Size)	Din (A-65)	Din (A-65)	Din (A-65)	Din (A-65)	Din (A-65)	Din (A-65)	Din (KS-56)
∘ Sea Side (t/wheel)	21 (8.3m x 4 Ws)	18 (7m x 4 Ws)	22.5 (5.25m x 4 Ws)	21.3 (5.25m x 4 Ws)	20 (6 m x 4 Ws)	25.7 (6 m x 4 Ws)	30 (12m x 16 Ws)
∘ Land Side (t/wheel)	21 (6 m x 4 Ws)	25.5 (7 m x 4 Ws)	12.5 (3 m x 2 Ws)	16.7 (5.25m x 2 Ws)	16.1 (4.5m x 2 Ws)	20.4 (4.5m x 2 Ws)	30 (12m x 12 Ws)
Total Weight (t)	110	131	76	Approx. 90	76	80	550
Owner	EMPORCHI	EMPORCHI	EMPORCHI	EMPORCHI	EMPORCHI	EMPORCHI	SAAM

Table III-2-3 Equipment Owned by EMPORCHI Other than Wharf Cranes

Equipment	Manufacturer (Country)		Capacity	Q'ty	Remarks
Forklift	CLARK	(Belgium)	16,500 lbs	1	
"	PETTIBONE	(USA)	16,500 lbs	3	
"	"	"	25,500 lbs	2	
"	YALE DPA-51	(UK)	6,000 lbs	30	
"	YALE KE-72	(UK)	5,000 lbs	21	
Tractor	COVENTRY	(UK)	10,000 lbs	14	
"	T.C.M	(Japan)	40,000 lbs	6	
Chassis	SOGECO	(Chile)	20/30 tons	7	
"	THOMAS	(USA)	2 tibs	200	
Forklift	TAYLOR	(USA)	52,000 lbs	2	For Container
Forklift	SUMITOMO	(Japan)	6,000 lbs	10	from Dec. '85

Table III-2-4 Service Utilities to Berths

Utilities \ Berth	1	2	3	4	5	6	7	8	9	10
Electricity	0	0	0	0	0	0	0	0	0	0
Water	0	0	0	0	0	0	0	0	0	0
Water to vessels	0	0	0	0	0	0	0	0	0	0
Lighting	0	0	0	0	0	0	0	0	0	0
Communication	T	T	T	T	T	T	T	T	C	C
Fire Fighting	0	0	-	-	-	X	-	X	-	-

0 = Available

T = Telephone available

C = Intercom available

\- = Not Provided

X = No longer available due to earthquake

(ii) Summary of Cargo Volume

According to the annual statistical report compiled by EMPORCHI, the total volume of cargoes handled at the port was about 1.6 million tons in 1984.

After 1981, when the peak of about 2.2 million tons was recorded, the cargo volume dropped drastically, but it has recently been recovering. On the other hand, through the period from 1962 to 1984, the foreign trade cargoes showed a tendency to increase against those for domestic trade. Especially, the export cargoes increased gradually year after year, as shown in Table III-2-5.

From the Table, the average growth rate per year from 1974 to 1984 is 1.8% for total foreign trade and 11.4% for exports.

As the cargoes for foreign trade comprise about 90% of the total cargoes, the Port of Valparaiso can be characterized as a foreign trade port.

2) Cargoes

(i) Commodities

The total cargo volume was about 1,575 thousand tons in 1984, and according to the cargo statistics by commodity, as shown in Table III-2-6, fruits were ranked as the first commodity. The share of fruits was about 30% of the total cargoes, industrial products about 17%, copper about 13% and food products also 13%.

As for the commodities of export cargoes, fruits were also first and copper came next. The share of these two reached 81% of the total export cargoes. On the other hand, as to the commodities of import cargoes, industrial products were ranked first with a share of 35%.

These results show that the major commodities handled at the Port of Valparaiso are fruits, copper and such general cargoes as industrial products.

Table III-2-5 Summary of Cargo Statistics at the Port of Valparaiso (1962 - 1984)

(tons)

	Foreign Trade			Domestic Trade	Transit	Total
	Import	Export	Sub-Total			
1962	519,832	112,177	632,009	688,232	14,762	1,335,003
1963	485,194	144,902	630,096	709,579	26,355	1,366,030
1964	416,449	140,820	557,269	664,278	6,087	1,227,634
1965	516,497	180,086	696,583	618,242	5,029	1,319,854
1966	678,490	150,036	828,526	548,983	6,372	1,383,881
1967	657,565	187,496	845,061	609,120	16,579	1,470,760
1968	709,613	227,332	936,945	510,630	15,947	1,463,522
1969	843,274	252,466	1,095,740	426,995	13,462	1,536,197
1970	732,300	256,583	988,883	419,220	365	1,408,468
1971	825,078	227,300	1,052,378	435,799	142	1,488,319
1972	927,489	183,659	1,111,148	318,955	-	1,430,103
1973	969,415	165,203	1,134,618	248,340	-	1,382,958
1974	909,721	257,341	1,167,062	312,146	-	1,479,208
1975	625,381	331,594	957,975	190,596	-	1,147,571
1976	498,249	439,014	937,263	244,404	-	1,181,667
1977	782,757	545,349	1,328,106	287,739	-	1,615,845
1978	844,292	546,478	1,390,770	267,393	-	1,658,163
1979	1,027,290	610,228	1,637,518	276,847	-	1,914,365
1980	1,095,079	612,659	1,707,738	351,991	-	2,059,729
1981	1,337,078	602,888	1,939,966	248,827	-	2,188,793
1982	684,586	603,466	1,288,052	162,155	-	1,450,207
1983	589,114	686,174	1,275,288	190,616	-	1,465,904
1984	645,734	756,944	1,402,678	173,018	-	1,575,696

Table III-2-6 Cargo Traffic by Commodity (1984) Port of Valparaiso

(tons)

Cod.	Commodity	Foreign Trade			Domestic Trade			Total
		Import	Export	Sub-total	Inward	Outward	Sub-total	
01	Fruits	48,810	419,725	468,535	7	458	465	469,000
02	Wheat	-	-	-	-	1	1	1
03	Corn	2	-	2	-	-	-	2
04	Fish meal	1,856	-	1,856	1,341	229	1,570	3,426
05	Celulose and Wood Pulp	849	105	954	-	-	-	954
06	Timber	279	9,103	9,382	239	315	554	9,936
07	Copper	16	193,383	193,399	16,482	-	16,482	209,881
08	Vehicles	12,392	145	12,537	1,258	705	1,963	14,500
09	Foodstuffs	91,373	57,295	148,668	43,975	16,535	60,510	209,178
10	Agricultural Products	4,437	11,390	15,827	-	25	25	15,852
11	Mineral Products	53,773	9,359	63,132	308	1,870	2,178	65,310
12	Industrial Products	223,474	11,814	235,228	1,481	28,216	29,697	264,985
13	Chemical Products	92,997	19,003	112,000	-	12,189	12,189	124,189
14	Others	115,476	25,622	141,098	6,022	41,362	47,384	188,482
	Total	645,734	756,944	1,402,678	71,113	101,905	173,018	1,575,696

Table III-2-7 Cargo Traffic by Commodity at Valparaiso Port 1981 - 1985

(tons, %)

Commodity \ Year	1981	1982	1983	1984	1985 (Jan~Oct)
01	386,425 (17.7)	380,237 (26.2)	396,372 (27.0)	471,815 (29.9)	533,223 (35.4)
02	-	-	-	1 (0)	-
03	95 (0)	218 (0)	242 (0)	1 (0)	27 (0)
04	4,732 (0.2)	10,194 (0.7)	8,884 (0.6)	3,373 (0.2)	6,360 (0.4)
05	2,335 (0.1)	1,095 (0.1)	3,566 (0.2)	953 (0.1)	34,139 (2.3)
06	3,219 (0.1)	7,691 (0.5)	10,918 (0.7)	10,038 (0.6)	5,811 (0.4)
07	266,618 (12.2)	239,600 (16.5)	272,012 (18.6)	209,290 (13.3)	246,639 (16.4)
08	134,024 (6.1)	24,837 (1.7)	12,599 (0.9)	14,406 (0.9)	11,688 (0.8)
09	129,576 (5.9)	176,482 (12.1)	180,902 (12.3)	209,281 (13.3)	167,595 (11.1)
10	51,076 (2.3)	19,851 (1.4)	13,248 (0.9)	14,882 (0.9)	13,262 (0.9)
11	183,137 (8.4)	47,741 (3.3)	40,109 (2.7)	66,912 (4.2)	55,560 (3.7)
12	92,119 (4.2)	182,798 (12.6)	277,571 (18.9)	262,992 (16.7)	210,115 (14.0)
13	90,331 (4.1)	116,139 (8.0)	132,166 (9.0)	123,295 (7.8)	95,631 (6.4)
14	845,107 (38.6)	243,324 (16.8)	117,315 (8.0)	188,458 (12.0)	124,828 (8.3)
Total	2,188,794 (100)	1,450,207 (100)	1,465,904 (100)	1,575,697 (100)	1,504,878 (100)

(ii) Container Cargoes

The container cargo volume and the number of containers handled at the port amount to 416 thousand tons and 42 thousand boxes respectively in 1984, as shown in Table III-2-8.

If the percentage of containerization is defined as the ratio of annual container cargo volume to the annual cargo volume of foreign trade, the percentage at the Port of Valparaiso has increased as shown in Table III-2-9.

The Table also shows that in 1984 the percentage of containerization is about 30%.

Table III-2-8 Container Cargo at the Port of Valparaiso (1979 - 1984)

		1979	1980	1981	1982	1983	1984
Volume (tons)	Total	185,388	292,737	479,166 (420,259)	346,652 (306,522)	332,159 (299,074)	416,446 (375,638)
	Inward	121,416	204,298	348,070 (336,157)	197,810 (188,655)	175,052 (163,453)	213,297 (197,757)
	Outward	63,978	88,439	131,096 (84,102)	148,842 (117,867)	157,107 (135,621)	203,149 (177,881)
Number (boxes)	Total	20,954	38,399	62,447 (35,671)	40,409 (23,898)	34,238 (20,740)	41,967 (25,842)
	Inward	12,957	20,707	34,836 (29,421)	19,644 (15,776)	17,217 (12,390)	21,200 (15,082)
	Outward	7,997	17,692	27,611 (6,250)	20,765 (8,122)	17,021 (8,350)	20,767 (10,760)

Note: Figures in parentheses are the volume and number of loaded containers

Table III-2-9 Percentage of Containerization

	Annual cargo volume of foreign trade (tons)	Annual container cargo volume (tons)	Percentage of containerization (%)
1979	1,637,518	185,388	11.3
1980	1,707,738	292,737	17.1
1981	1,939,966	479,166	24.7
1982	1,288,052	346,652	26.9
1983	1,275,288	332,159	26.0
1984	1,402,678	416,446	29.7

3) *Ship Movement*

As for vessels calling at the Port of Valparaiso in 1983, the number of ships and the average gross tonnage of those vessels are 742 vessels and 8,600 G/T respectively, as shown in Table III-2-10.

The Table also shows that the average size of vessels has become larger year after year.

As for the type of vessels, from 1981 to 1985, conventional cargo ships for general cargo and refer ships for fruit comprise more than 70 percent of the total number of ships, as shown in Table III-2-11. Fig. III-2-3 shows the distribution of ship size by type. The major class of conventional cargo ships is 10,000 - 20,000 DWT.

Table III-2-10 The Number and Average Tonnage of Ships at the Port of Valpariso (1962 - 1985)

	National Vessels				Foreign Vessels				Total			
	N° of Ships	Net Tonnage	Gross Tonnage	Length	N° of Ships	Net Tonnage	Gross Tonnage	Length	N° of Ships	Net Tonnage	Gross Tonnage	Length
1962	436	1,819	nd	nd	660	3,730	nd	nd	1,096	2,970	nd	nd
1963	525	1,877	nd	nd	673	3,909	nd	nd	1,198	3,019	nd	nd
1964	447	1,840	nd	nd	599	3,890	nd	nd	1,046	3,014	nd	nd
1965	381	2,031	nd	nd	726	4,003	nd	nd	1,107	3,324	nd	nd
1966	437	2,426	nd	nd	687	3,515	nd	nd	1,124	3,092	nd	nd
1967	338	1,421	nd	nd	860	3,997	nd	nd	1,198	3,270	nd	nd
1968	305	1,317	nd	nd	800	4,119	nd	nd	1,105	3,346	nd	nd
1969	229	1,348	nd	nd	844	4,350	nd	nd	1,073	3,709	nd	nd
1970	193	1,715	nd	nd	736	4,474	nd	nd	929	3,901	nd	nd
1971	174	1,764	nd	nd	655	4,603	nd	nd	829	4,007	nd	nd
1972	161	1,666	nd	nd	584	4,366	nd	nd	745	3,783	nd	nd
1973	155	2,757	nd	nd	509	4,520	nd	nd	664	4,108	nd	nd
1974	270	nd	4,287	nd	403	nd	8,407	nd	673	nd	6,754	nd
1975	235	nd	5,666	nd	473	nd	8,678	nd	708	nd	7,678	nd
1976	284	nd	5,900	127.4	459	nd	8,548	143.9	743	nd	7,536	137.6
1977	329	nd	6,115	133.2	557	nd	8,616	142.3	886	nd	7,687	138.9
1978	203	4,345	7,178	126.8	616	4,993	7,879	141.9	819	4,832	7,705	141.2
1979	300	nd	6,459	131.2	659	nd	7,607	144.2	959	nd	7,248	140.1
1980	264	nd	6,479	122.4	736	nd	7,802	143.7	1,000	nd	7,453	138.1
1981	204	nd	7,884	133.0	899	nd	8,326	145.0	1,103	nd	8,244	142.8
1982	108	nd	7,556	130.8	816	nd	9,129	162.0	924	nd	8,945	158.4
1983	96	nd	6,015	112.8	646	nd	8,979	145.9	742	nd	8,596	141.6

nd: no data

Table III-2-11 Distribution of vessels by type and by class at Valparaiso port, 1981 - 1985

Port: Valparaiso Year: 1985/Jan. - Oct.

Type \ DWT	-499	500 999	1000 1999	2000 2999	3000 3999	4000 4999	5000 5999	6000 6999	7000 7999	8000 8999	9000 9999	10000 14999	15000 19999	20000 24999	25000 29999	30000 -	Total
Conventional cargo	14	0	1	3	11	3	2	7	8	4	8	134	90	8	4	2	299
Full Container	0	0	0	1	16	18	2	0	0	0	0	0	0	19	0	0	56
Semi Container	0	0	0	0	0	0	0	0	0	0	9	33	15	6	0	0	63
Bulk Ore	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Bulk Wheat	0	0	0	0	0	0	0	0	0	0	0	0	0	3	5	1	9
Bulk Liquid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refer	0	1	0	1	4	19	12	19	6	24	44	40	0	0	0	0	170
Fishing Vessels	0	2	11	4	8	3	0	0	0	0	0	0	0	0	0	0	28
RO-RO	0	0	0	0	0	0	0	7	17	0	0	0	0	0	0	0	24
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	14	4	12	9	39	43	16	33	31	28	61	207	105	36	9	3	650

Port: Valparaiso Year: 1984

Type \ DWT	-499	500 999	1000 1999	2000 2999	3000 3999	4000 4999	5000 5999	6000 6999	7000 7999	8000 8999	9000 9999	10000 14999	15000 19999	20000 24999	25000 29999	30000 -	Total
Conventional cargo	3	0	7	6	20	15	0	1	19	4	4	158	101	15	0	0	353
Full Container	0	0	0	0	11	32	0	1	2	0	0	0	2	1	0	0	49
Semi Container	0	0	0	0	0	0	0	0	1	7	13	31	13	7	0	0	72
Bulk Ore	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
Bulk Wheat	0	0	0	0	0	0	0	0	2	0	0	1	0	0	4	2	9
Bulk Liquid	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Refer	0	0	1	0	13	19	25	20	7	29	67	21	0	0	0	0	202
Fishing Vessels	8	1	18	3	14	0	0	0	0	0	0	0	0	0	0	0	44
RO-RO	0	0	0	0	0	2	0	12	5	0	0	2	1	0	0	0	22
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51
Total	11	1	26	10	58	68	25	34	36	40	84	213	117	23	6	2	805

Port: Valparaiso Year: 1983

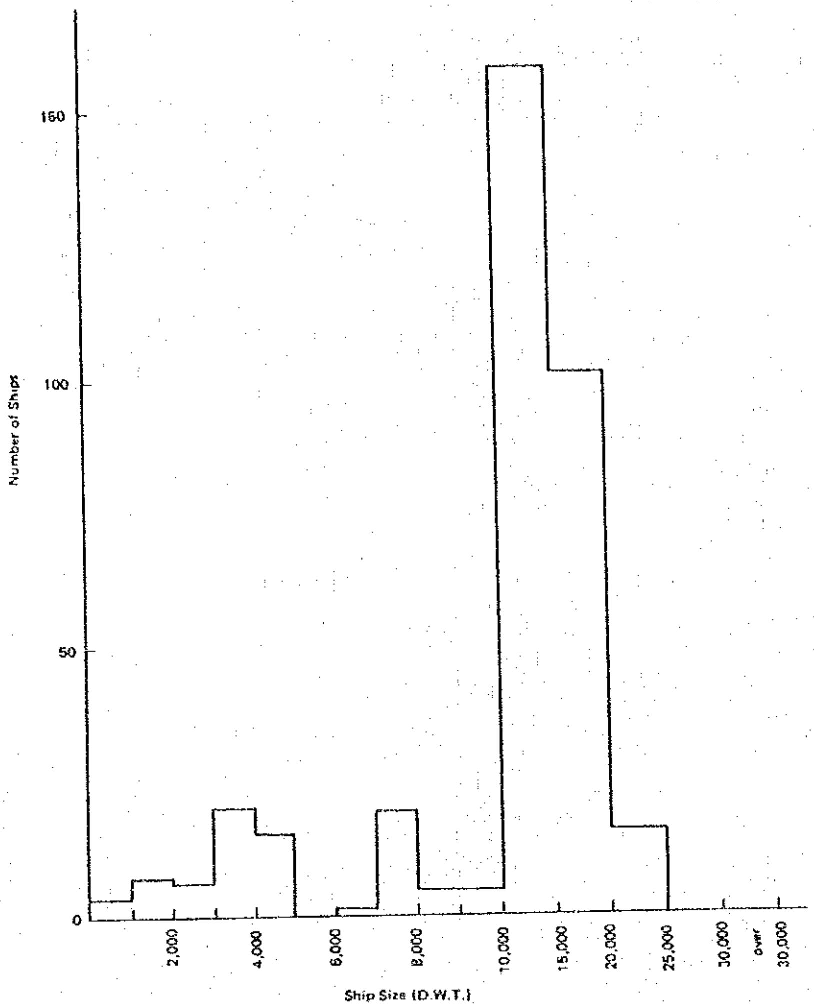
Type \ DWT	-499	500 999	1000 1999	2000 2999	3000 3999	4000 4999	5000 5999	6000 6999	7000 7999	8000 8999	9000 9999	10000 14999	15000 19999	20000 24999	25000 29999	30000 -	Total
Conventional Cargo	0	1	5	8	3	32	2	7	10	11	7	191	116	15	3	0	411
Full Container	0	0	2	0	0	27	0	0	0	0	0	0	1	0	0	0	30
Semi Container	0	0	0	0	0	0	0	0	0	7	12	23	18	5	3	0	68
Bulk Ore	0	0	0	0	0	0	0	0	6	0	0	1	2	1	1	2	13
Bulk Wheat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4
Bulk Liquid	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	2
Refer	0	0	0	1	20	17	12	7	16	13	31	26	0	0	0	0	143
Fishing Vessels	1	0	24	1	10	0	0	0	0	0	0	0	0	0	0	0	36
RO-RO	0	0	0	0	0	1	0	5	1	0	0	0	1	0	4	2	14
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43
Total	1	1	31	10	33	77	15	19	34	31	50	241	138	21	11	8	764

Port: Valparaiso Year: 1982

Type \ DWT	-499	500 999	1000 1999	2000 2999	3000 3999	4000 4999	5000 5999	6000 6999	7000 7999	8000 8999	9000 9999	10000 14999	15000 19999	20000 24999	25000 29999	30000 -	Total
Conventional cargo	2	2	6	5	12	31	3	13	24	25	26	237	128	31	1	0	546
Full Container	0	0	0	0	0	25	0	0	0	3	1	0	3	4	0	0	36
Semi Container	0	0	0	0	0	0	0	1	0	5	16	53	13	3	4	0	95
Bulk Ore	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	4
Bulk Wheat	0	0	0	0	0	0	0	0	0	0	4	0	2	0	9	2	17
Bulk Liquid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refer	0	0	0	4	19	21	5	8	12	19	38	11	0	0	0	0	137
Fishing Vessels	0	0	30	4	5	0	0	0	0	0	0	0	0	0	0	0	39
RO-RO	0	0	0	0	0	0	0	13	0	1	0	0	3	0	4	1	22
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	61
Total	2	2	36	13	36	77	8	35	40	53	85	301	149	38	18	3	957

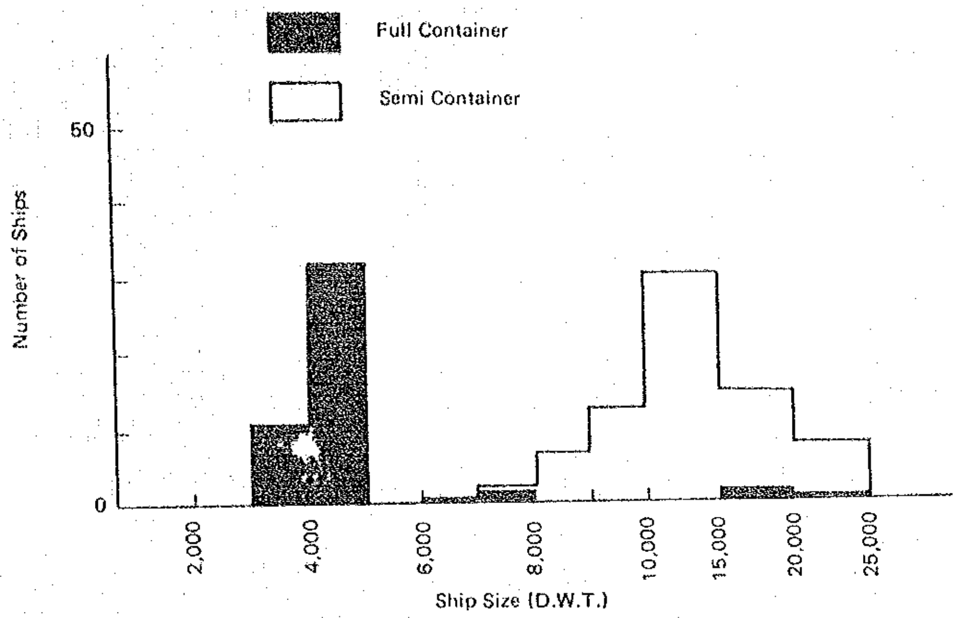
Port: Valparaiso Year: 1981

Type \ DWT	-499	500 999	1000 1999	2000 2999	3000 3999	4000 4999	5000 5999	6000 6999	7000 7999	8000 8999	9000 9999	10000 14999	15000 19999	20000 24999	25000 29999	30000 -	Total
Conventional cargo	0	3	7	11	42	40	2	10	29	21	30	266	178	30	17	0	686
Full Container	0	0	0	1	0	25	0	1	0	3	0	0	0	0	0	0	30
Semi Container	0	0	0	0	0	0	0	1	0	5	15	51	8	7	3	1	91
Bulk Ore	0	0	0	0	0	0	0	0	5	0	0	0	4	0	0	0	9
Bulk Wheat	0	0	0	0	0	0	0	0	0	0	7	3	6	10	8	11	45
Bulk Liquid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refer	0	0	3	1	19	18	15	16	6	15	27	15	2	0	0	0	137
Fishing Vessels	0	0	23	5	6	0	0	0	0	0	0	0	0	0	0	0	34
RO-RO	0	0	0	5	0	0	0	15	0	0	0	0	2	0	0	0	22
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26
Total	0	3	33	23	67	83	17	43	40	44	79	335	200	47	28	12	1080

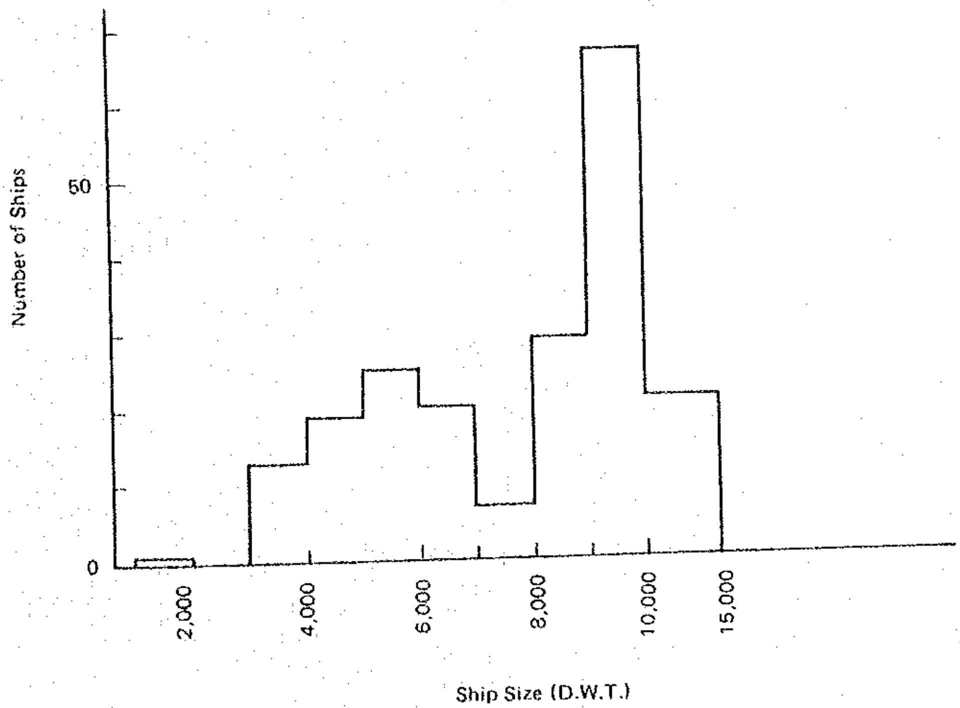


(a) Conventional Cargo Ships

Fig. III-2-3 (a) Distribution of Ship Size (1984)



(b) Container Cargo Ships



(c) Refer Cargo Ships

Fig. III-2-3 (b, c) Distribution of Ship Size (1984)

4) Use of Berths - Before and After Earthquake

Table III-2-12 shows the condition of berth usage at the Port of Valparaiso and Fig. III-2-4 shows the berth occupancy rate from 1981 to 1985. These figure show that berths No.1 - 8 are used more frequently and berths No.9 and 10 are used less frequently. Comparing data before and after the earthquake, the use of berths 1 - 4 is increasing, but the use of berths 5 - 8 is decreasing because of the earthquake damage.

Table III-2-12 Condition of Berth Usage at Valparaiso Port (Comparison of Berth Usage Before and After Earthquake)

(1) Year 1981 - 1984 (average)

Berth No.	Length (m)	Depth (m)	Annual Berthing Hours	Berth Occupancy (%)	Annual Cargo Handling Volume(tons)	Cargo Handling Volume Per Metre
1	175	-10	5,220	59.6	227,967	1,303
2	175	-10	5,144	58.8	296,127	1,692
3	260	-11	5,592	63.8	294,683	1,133
4	200	-10	2,962	33.8	114,026	570
5	165	-10	3,125	35.8	127,554	773
6	245	-9	4,638	52.9	206,342	842
7	120	-7.5	3,328	38.0	43,530	363
8	240	-9	5,641	64.4	248,500	1,035
9	220	-10	1,449	16.5	109,600	498
10	205	-5.1	196	2.2	1,813	9
Total	2,005				1,670,150.5	833

(2) Year 1985 (Jan. to Oct.)

Berth No.	Length (m)	Depth (m)	Annual Berthing Hours	Berth Occupancy (%)	Annual Cargo Handling Volume(tons)	Cargo Handling Volume Per Metre
1	175	-10	3,860	52.9	232,574	(1,329.0) 1,594.8
2	175	-10	4,534	62.1	313,148	(1,789.4) 2,147.3
3	260	-11	4,364	59.8	251,507	(967.3) 1,160.8
4	200	-10	2,815	38.6	281,973	(1,410.0) 1,692.0
5	165	-10	1,584	21.7	78,751	(477.3) 572.8
6	245	-9	3,025	41.5	120,097	(490.2) 588.2
7	120	-7.5	985	13.5	8,589	(71.6) 85.9
8	240	-9	3,062	42.0	116,135	(483.9) 580.7
9	220	-10	1,584	21.7	98,978	(449.9) 539.9
10	205	-5.1	107	1.5	3,126	(15.2) 18.2
Total	2,005				1,504,878	(750.6) 900.7

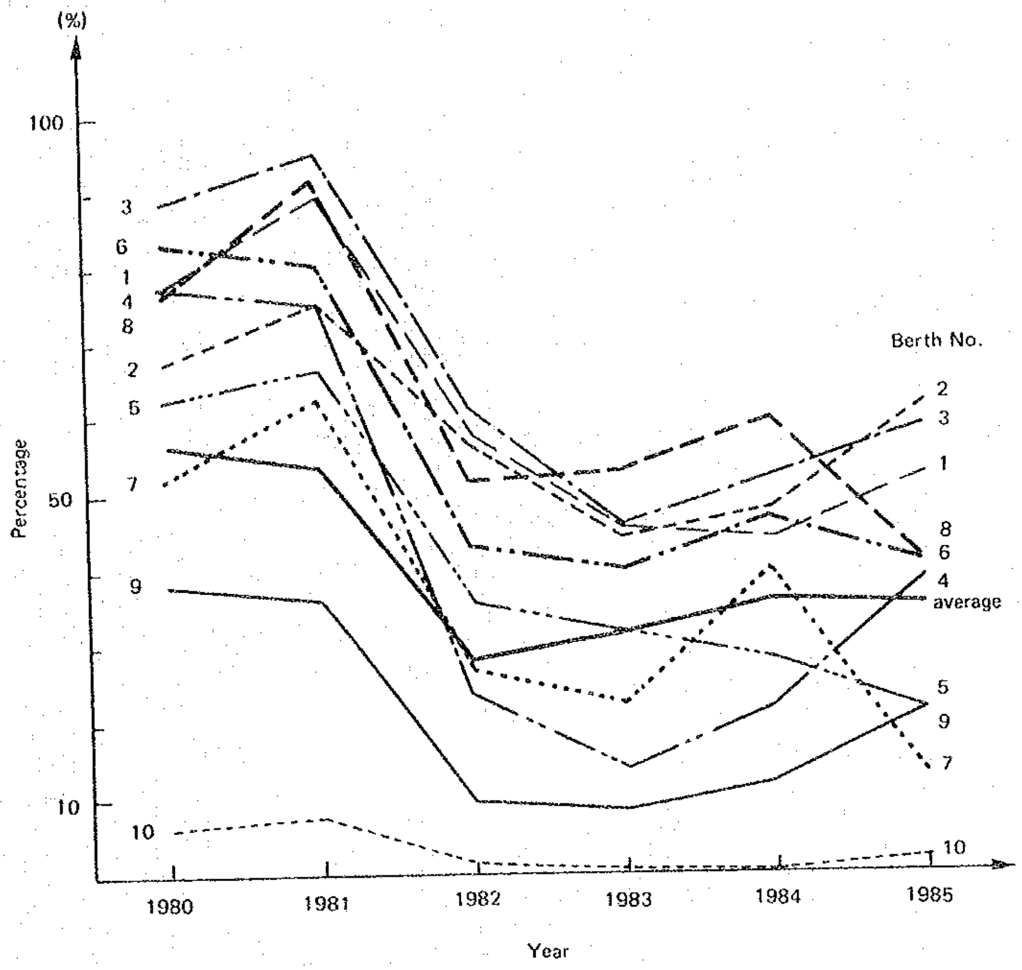


Fig. III-2-4 Rate of Berth Occupancy (Valparaiso)

The usage of each berth before and after the earthquake is summarized in Table III-2-13.

Table III-2-13 Summary of Berth Usage in Valparaiso Port (Preliminary)

Berth N°	Before Earthquake	After Earthquake	Remarks
1	Priority to liner vessels for foreign trade	Priority to liner vessels for foreign trade	Shortage of handling yard
2	ditto	ditto	ditto
3	ditto	ditto	
4	Priority to container vessels	Priority to container vessels	Shortage of stock yard
5	-	-	Insufficient water depth; siltation
6	Tramper (Priority to chartered vessels for fruits)	Tramper (Priority to chartered vessels for fruits)	Deterioration of cargo handling capacity
7	ditto	ditto	Lack of cranes
8	ditto	ditto	Deterioration of cargo handling capacity
9 : 10	Domestic trade reserved berths	non-use	Deterioration of facility

There are some problems as follows:

① Because of siltation, berths No 4 and No 5 are not in full use.

② Additional handling and stocking yards for cargoes, especially for containers, are needed.

③ In the congested season (normally the summer season), the number of berths is insufficient.

(2) Port of San Antonio

1) Outline

(i) Port Facilities

i) Harbor and Berthing Facilities

The Port of San Antonio is located in the city of San Antonio with a population of 60 thousand, and it is about 110 km by road and about 120 km by railway due west from Santiago. This is the nearest port to the Metropolitan Region, and therefore it can be considered as a very important port in Chile, as is the Port of Valparaiso.

As for the harbor facilities, the harbor entrance is about 400 m wide with a water depth of over 10 m. Of this, there is an area about 250 m wide with a water depth of over 15 m. On the other hand, the length of ships with a full load draft of 15 m is 250 m, so the width and depth of the waterway are sufficient at present as calling ships seldom pass each other. However, the length of part of the harbor entrance is not sufficient considering the stopping distance of vessels. Table III-2-14 shows the standard widths of waterways in Japan.

Table III-2-14 Widths of Waterways

(L is the overall length of the ship)

Length of Waterways	Condition of Navigation	Width
Relatively long waterways	Waterways where ships pass by each other frequently	2 L
	Other waterways	1.5 L
Waterways other than the above	Waterways where ships pass by each other frequently	1.5 L
	Other waterways	L

The port has a calm sea area protected by the 800 m breakwater, and there are 7 berths which have water depths of -7 m to -10 m. The total length of these berths is 1,305 m, but only 6 berths are available at present because berth No.3 is being reconstructed. As for the storage spaces before the earthquake, there were two sheds and open storage yards of about 52 thousand m2 just behind the berths, and there were also two warehouses and open storage yards of about 79 thousand m2 in the port.

The main port facilities before the earthquake are listed in Table III-2-15.

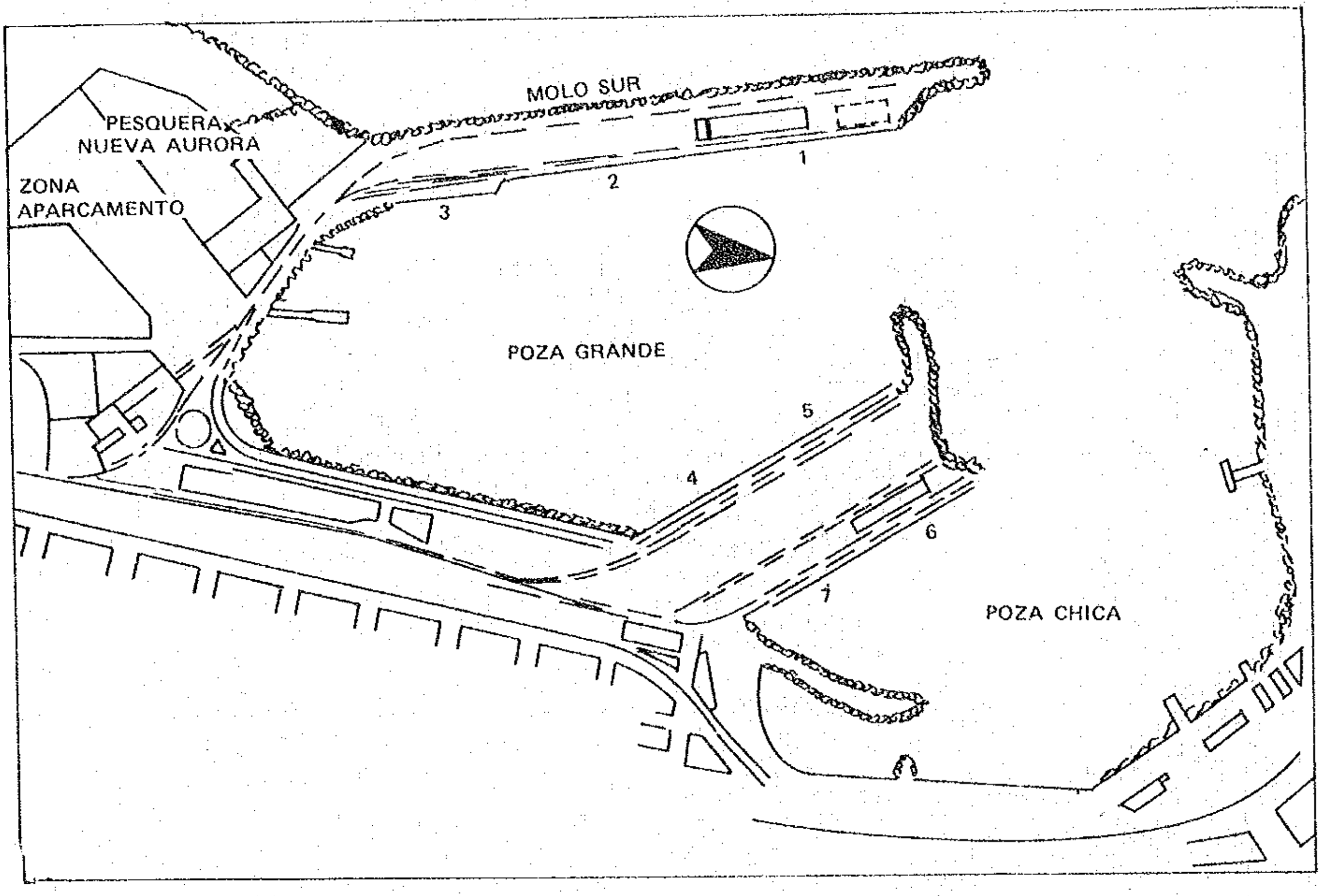


Fig. III-2-5 Plan of the Port of San Antonio

Table III-2-15 Port Facilities (Port of San Antonio)

(as of 1984)

Berths	1/2	3 (Under reconstruction)	4	5	6	7	Tanker berth	Total
Length (m)	452	200	383		200	120		1,355
Water Depth (m)	-10	-8	-10		-8.53	-7		
Width of Apron (m)	20/35	35	35		35	35		
Number of Cranes	6	-	-		4	2		12
Transit Sheds	1 row (4,270 m^2)	-	-		1 row (3,750m2)	-		2 ros (8,020m^2)
Open Storage Yard (m^2)	6,720	5,095	32,619		3,922	3,459		51,815
Year of Completion	1918 - 1935	1980 - 1983	1971 - 1977	1977 - 1979	1911 - 1918	1957 - 1963		
Type of Structure	Concrete block gravity wall	Anchored sheet pile wall	Anchored sheet pile wall	Open type on steel pipe pile	Open type on H-shaped Steel piles or concrete piles		Detached offshore jetty	
Water depth at present (m)	10	2.5 - 6.0	10	10	8.5	7.0	10.0	
Copeline height (m)	+4.9	+4.9	+4.9	+4.9	+4.9	+4.6		

Source: Manual de los Puertos Operados por la Empresa Portuaria de Chile, 1984

ii) Handling Facilities and Equipment

The specifications of wharf cranes are tabulated in Table III-2-16. Equipment other than the wharf cranes owned by EMPORCHI is listed in Table III-2-17. These items were not damaged at all by the earthquake on 3/31/85.

Additionally, the private sector owns various handling equipment, notably mobile cranes and forklifts owned by AGUNSA. Specifications are:

Mobile Cranes

- Capacity = 50 t x 14 m
- Weight = 180 t
- Manufacturer = DEMAG (Germany)
- Number = 2

Forklifts for 40 ft containers

- Capacity = 85,000 lbs
- Manufacturer = TAYLOR (USA)
- Number = 2

Provision of utilities at present is shown in Table III-2-18. It can be seen that most of the utility services at berths No.1 - 3 have been damaged and can no longer be used, and some of the utilities at berths No. 4 & 5 were damaged as well.

Table III-2-16 The Specifications of Wharf Cranes

Items \ Type of Crane	Portal Rope Balance A	Portal Rope Balance B	Portal Rope Balance C	Portal Double Link D	Portal Rope Balance E	Portal Rope Balance F
Number (15) Before Earthquake	2	2	2	1	6	2
Number (11) After Earthquake	2	0	0	1	6	2
Manufacturer (Country)	ELYMA (Spain)	MAN (Germany)	MAN (Germany)	APPLEVAGE (France)	APPLEVAGE (France)	ELYMA (Spain)
Year of Construction/ operation	1970 (con) 1972 - 3 (Op)	1972 At Port Montt 1982 (Op)	1972 At Port Montt 1980 (Op)	1960	1963 (op)	1970 (Con) 1972 (Op)
Design Condition	Wind 50 kt	Wind 50 kt	Wind 50 kt		Wind 50 kt	Wind 50 kt
Rated Load (t)	7.5	5	3	10	5	6
Outreach (m)	19,375	15,375	15,375		15,375	19,375
Radius (Max/Min) (n)	22/7	18/7	18/7		18/7	22/7
Rail Gauge (m)	5.25	5.25	5.25	10	5.25	5.25
Lift Range (Above/Below Ra:)(m)		23/20	23/20		23/15	
Approx. Wheel Load (t/wheel)	2 (5.25m x 4Ws) (5.25m x 4Ws)	26 (5.25m x 4Ws) (5.25m x 4Ws)	20 (5.25m x 2Ws) (5.25m x 2Ws)	23 (6 Ws) (4 Ws)	16.8 (5.25m x 4Ws) (5.25m x 4Ws)	22 (5.25m x 4Ws) (5.25m x 4Ws)
Approx. Total Weight (t)	100	80	80	200	70	90
Owner	EMPORCHI	EMPORCHI	EMPORCHI	SAAM	EMPORCHI	EMPORCHI

Table III-2-17 Equipment Other than Wharf Cranes Owned by Emporchi

Equipment	Manufacturer (Country)	Capacity	Q'ty	Remarks
Forklift	HYSTER (USA)	62,000 lbs	1	For containers
"	YALE (Japan)	3.2 ton	4	
Chute			1	For bulk
Yard Locomotive	DEUTZ A8M-428 (Germany)	10 ton	2	
	DEUTZ V6M-536 (Germany)	15 ton	1	
Tractor Locomotive	WHITTING (USA)	15,000 lbs	1	Two Directions
"	"	30,000 lbs	1	Tire/steel wheel
Shuttle Wagon	ISCO (USA)	15,000 lbs	1	One direction Tire/steel wheel

Table III-2-18 Service Utilities at Berths

	1	2	3	4	5	6	7
Electricity	X	X	-	O	O	O	O
Water	X	X	X	X	X	O	O
Water to vessels	X	X	X	X	X	O	O
Lighting	-	X	X	O	O	O	O
Communication	X	X	X	-	-	O	O
Fire Fighting	X	X	-	X	X	-	-

O = Available

\- = Not Provided

X = No longer available due to earthquake

(ii) Summary of Cargo Volume

The total cargo volume handled at the port of San Antonio amounted to 2,314 thousand tons in 1984, and this was the largest volume among all the ports managed by EMPORCHI. The total volume of foreign cargoes increased from 806 thousand tons in 1974 to 2,204 thousand tons in 1984. This is a growth of 270% with an average growth rate per year of 10.6% over the ten years (Table III-2-19). As for foreign cargoes, imports have grown especially rapidly since the liberalization of imports was adopted as a basic policy by the Government in 1978. For import cargoes, the volume was 538 thousand tons in 1977 and 1,074 thousand tons in 1978 which was twice the volume the previous year. On the other hand, export cargoes have grown steadily from 207 thousand tons in 1974 to 773 thousand tons in 1984.

The total volume of domestic cargoes has decreased over time to less than 110 thousand tons in 1984 (Table III-2-19).

Table III-2-19 Summary of Cargo Statistics Port of San Antonio
1962 - 1984

(tons)

	Foreign Trade			Domestic Trade	Transit Cargo	Total
	Import	Export	Sub-Total			
1962	188,494	234,112	422,606	289,284	-	711,890
1963	136,177	230,181	366,358	379,884	-	746,242
1964	220,495	274,332	494,827	435,762	-	930,589
1965	320,570	233,984	554,554	416,731	-	971,285
1966	301,063	241,309	542,372	412,830	-	955,202
1967	298,542	219,851	518,393	304,258	217	822,868
1968	365,650	210,834	576,484	317,616	62	894,162
1969	453,723	197,256	650,979	250,849	-	901,828
1970	430,883	240,472	671,355	177,638	-	848,993
1971	434,602	209,870	644,472	189,054	-	833,526
1972	621,354	197,610	818,964	123,313	-	942,277
1973	869,039	106,182	975,221	193,429	-	1,168,650
1974	599,046	206,568	805,614	114,334	-	919,948
1975	527,541	303,351	830,892	102,960	-	933,852
1976	837,214	396,688	1,233,902	101,628	-	1,335,530
1977	538,271	510,656	1,048,927	87,825	-	1,136,752
1978	1,073,629	451,014	1,524,643	83,914	-	1,608,557
1979	1,086,411	480,392	1,566,803	76,364	-	1,643,167
1980	1,504,952	524,387	2,029,339	65,184	-	2,094,523
1981	1,549,438	562,129	2,111,567	57,612	-	2,169,179
1982	1,577,231	759,223	2,336,454	101,928	-	2,438,382
1983	1,395,805	732,213	2,128,018	65,930	-	2,193,948
1984	1,431,265	772,913	2,204,178	109,798	-	2,313,976

Source: Manual de los Puertos Operados por la Empresa Portuaria de Chile, 1984

2) Cargoes

(i) Commodities

The cargo volume by commodity in 1984 is shown in Table III-2-20. Among the export cargo commodities, copper is ranked No 1 and fruits come next. On the other hand, among the import cargo commodities, wheat is ranked first, chemical liquids second and sugar third. The share of the two leaders, copper (17.4%) and grain (38.3%), comprise about 56% of the total cargoes. Thus, at the port of San Antonio, bulk cargoes comprise about 60% of the total cargoes.

The composition of the commodities of foreign trade in 1980 and in 1984 are shown in Tables III-2-21 and 22. We note that no major changes have occurred over the five years except for a sharp decrease of corn. Overall, the port of San Antonio is a port specializing in bulk cargoes including copper.

Table III-2-20 Cargo Traffic by Commodity (1984) Port of San Antonio

(tons)

Cod.	Commodity	Foreign Trade		Sub-total	Domestic Trade		Sub-total	Total
		Import	Export		Inward	Outward		
01	Fruits	1,992	96,458	98,450	-	-	-	98,450
02	Wheat	848,628	-	848,628	-	-	-	848,628
03	Corn	33,840	-	33,840	-	-	-	33,840
04	Fish Meal	3,865	-	3,865	-	-	-	3,865
05	Cellulose and Wood Pulp	-	10,855	10,855	-	-	-	10,855
06	Timber	-	3,413	3,413	35	-	35	3,448
07	Copper	-	401,747	401,747	-	-	-	401,747
08	Vehicles	1,120	1,516	2,636	26	-	26	2,662
09	Foodstuffs	116,170	3,734	119,904	19,832	-	19,832	139,736
10	Agriculture Products	15,144	27,092	42,236	14,805	-	14,805	57,041
11	Mineral Products	9,553	47,494	57,047	66,813	-	66,813	123,860
12	Industrial Products	36,014	4,997	41,011	74	-	74	41,085
13	Chemical Products	178,181	4,489	182,670	1,996	-	1,996	184,666
14	Others	186,758	171,118	357,876	4,158	2,059	6,217	364,093
	Total	1,431,265	772,913	2,204,178	107,739	2,059	109,798	2,313,976

Source: Manual de los Puertos Operodos por la Empresa Portuaria de Chile, 1984

Table III-2-21 The Share of Main Export Cargoes by Commodity

Year	1980		1984	
Commodities	Copper	52.7%	Copper	52.0%
	Fruit	9.1%	Fruit	12.5%
	Agricultural Products	7.0%	Mineral Products	6.1%
	Foodstuffs	1.1%	Agricultural Products	3.5%
	Others	25.1%	Others	22.1%

Table III-2-22 The Share of Main Import Cargoes by Commodity

Year	1980		1984	
Commodities	Wheat	53.5%	Wheat	59.3%
	Corn	21.2%	Chemical Products	12.5%
	Foodstuffs	8.2%	Foodstuffs	8.1%
	Chemical Products	4.9%	Industrial Products	2.5%
	Others	4.7%	Others	13.1%

(ii) Container Cargoes

Table III-2-23 shows the tonnage and number of container cargoes handled over six years. The number of containers steadily increased from 1,113 in 1979 to 20,966 in 1984. The group of CCNI (Cia. Chilena de Nav. Interoceanica), K. Line (Kawasaki Kisen Kaisha) and NYK Line (Nippon Yusen Kaisha) started to service the Port of San Antonio in 1981, so the number of containers shows an abrupt increase. 1984 was also a special year since the containers ships of EUROSAL called only at San Antonio due to a conflict concerning their return cargo (copper). From this it may be noted that in 1984 the Port of San Antonio showed an abrupt increase (1.8 times) in the number of containers handled.

Nevertheless, neither special handling space for containers nor specialized container berths have been provided in response to the containerization

Table III-2-23 Movement of Container Cargo at the Port of San Antonio (1979 - 1984)

		1979	1980	1981	1982	1983	1984
Volume (tons)	Total	9,224	10,708	79,446 (61,274)	140,925 (138,693)	130,978 (123,521)	222,108 (203,661)
	Inward	4,622	3,294	49,403 (39,473)	47,232 (46,313)	43,460 (40,292)	135,764 (133,183)
	Outward	4,602	7,414	30,043 (21,801)	93,693 (92,380)	86,618 (83,229)	86,334 (70,478)
Number	Total	1,113	1,430	9,445 (5,783)	8,837 (7,879)	11,819 (9,730)	20,966 (14,089)
	Inward	499	459	5,372 (3,751)	3,784 (3,385)	5,430 (4,415)	11,103 (10,183)
	Outward	614	971	4,073 (2,032)	5,053 (4,494)	6,389 (5,315)	9,863 (3,906)

Figures in parentheses are the volume and number of loaded containers.

3) Ship Movement

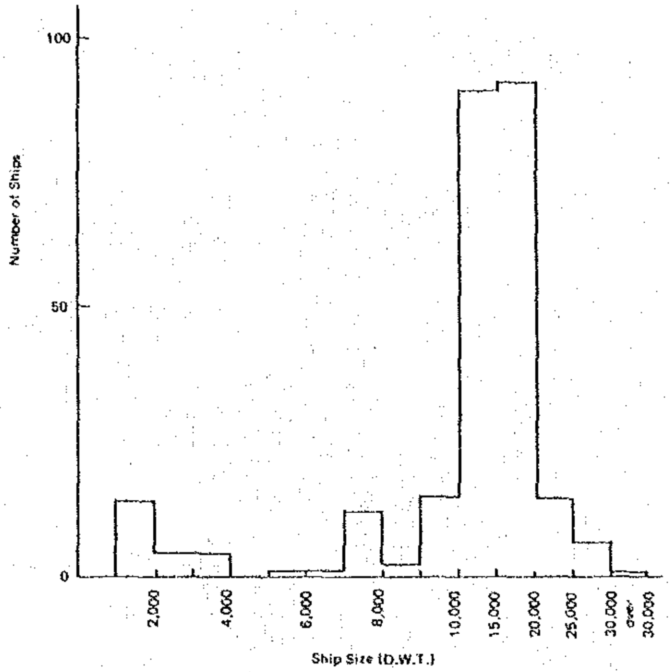
Based upon the records of vessels calling at the Port of San Antonio, the number of ship calls and the average gross tonnages of oceangoing vessels were 417 and 11,093 G/T respectively in 1983. As shown in Table III-2-24, the size of calling vessels increased, which is common throughout the world. A total of 428 ships called during 1984. Of these, 255 ships were conventional cargo ships, 87 ships were bulk carriers for grain and liquid bulk cargoes, 54 ships were full and semi-container ships and the remaining 32 ships were refer ships for fruit and Ro-Ro ships. About 80% of the total vessels were general cargo carriers including container ships and about 20% were bulk carriers.

The number of ships by size is shown Fig. III-2-6. The main size of conventional cargo ships was 10,000 - 20,000 DWT. As for grain ships, the dominant size was over 30,000 DWT, and most of the container ships were in the range of 10,000 - 25,000 DWT.

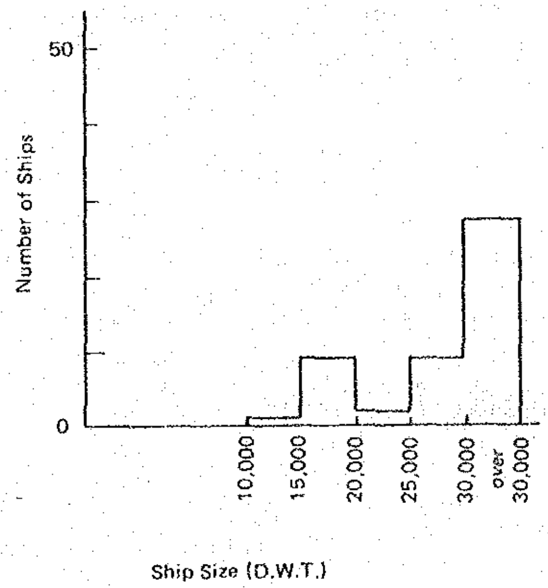
Table III-2-24 The Number and Average Tonnage of Ships at the Port of San Antonio (1962 - 1983)

	National Vessels				Foreign Vessels				Total			
	N° of Ships	Net Tonnage	Gross Tonnage	Length	N° of Ships	Net Tonnage	Gross Tonnage	Length	N° of Ships	Net Tonnage	Gross Tonnage	Length
1962	608	1,529	nd	nd	483	4,059	nd	nd	1,091	2,649	nd	nd
1963	727	1,520	nd	nd	643	4,193	nd	nd	1,370	2,775	nd	nd
1964	374	1,630	nd	nd	316	4,232	nd	nd	690	2,822	nd	nd
1965	351	1,521	nd	nd	339	3,656	nd	nd	690	2,570	nd	nd
1966	332	1,669	nd	nd	306	4,397	nd	nd	638	2,978	nd	nd
1967	281	1,847	nd	nd	318	4,257	nd	nd	599	3,126	nd	nd
1968	240	2,058	nd	nd	322	4,256	nd	nd	562	3,329	nd	nd
1969	160	2,183	nd	nd	312	4,490	nd	nd	472	3,708	nd	nd
1970	171	2,748	nd	nd	255	4,638	nd	nd	426	3,879	nd	nd
1971	118	3,298	nd	nd	212	4,848	nd	nd	330	4,294	nd	nd
1972	93	2,858	nd	nd	217	5,690	nd	nd	310	4,840	nd	nd
1973	108	3,109	nd	nd	174	6,681	nd	nd	282	5,313	nd	nd
1974	82	nd	5,936	nd	140	nd	11,346	nd	222	nd	9,348	nd
1975	96	nd	6,947	nd	196	nd	9,928	nd	292	nd	8,948	nd
1976	99	nd	6,770	nd	227	nd	10,048	nd	326	nd	9,053	nd
1977	100	nd	7,418	nd	258	nd	9,125	nd	358	nd	8,648	nd
1978	84	5,189	8,632	141.4	249	6,519	10,494	158.4	333	6,184	10,024	154.1
1979	99	4,511	7,283	128.6	236	7,016	11,239	156.6	335	6,276	10,070	148.3
1980	104	5,016	8,104	135.7	278	6,653	10,691	152.2	382	6,208	9,987	148.1
1981	102	5,679	8,651	136.3	339	6,814	11,141	155.3	441	6,551	10,565	150.9
1982	107	5,440	8,522	136.0	337	7,122	11,411	157.1	444	6,717	10,715	152.0
1983	75	nd	7,628	130.4	342	nd	11,853	156.1	417	nd	11,093	151.5

nd: no data

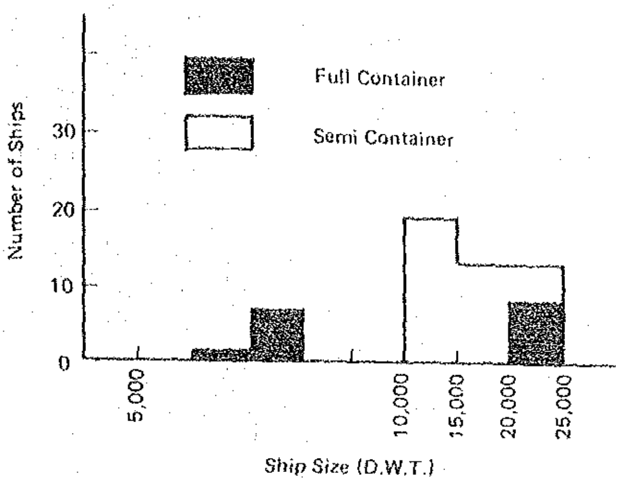


(a) Conventional Cargo Ships

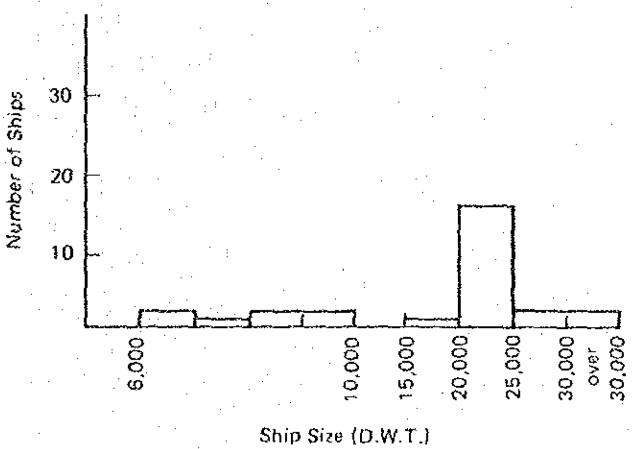


(b) Grain Ships

Fig. III-2-6 (a, b) Distribution of Ship Size (1984)



(c) Container Ships



(d) Liquid Bulk Ships

Fig. III-2-6 (c, d) Distribution of Ship Size (1984)

4) Berth Occupancy

Table III-2-25 shows the rate of berth occupancy by berth over five years.

We note from this Table that berth No.1 was efficiently used before the earthquake. However, the other berths were not used efficienty: especially berths No.4 and No.7 show a low occupancy of only about 10 - 30%.

Thus, the present capacity of the Port of San Antonio exceeds the present demand.

Table III-25 Rate of Berth Occupancy

Berth \ Year	1980	1981	1982	1983	1984	Average for 5 years
1	75.7	64.2	67.0	60.4	66.3	66.7
2	50.1	60.3	57.8	43.6	58.7	54.1
4	25.7	27.5	31.7	20.1	33.0	27.6
5	38.4	50.0	28.8	27.5	36.1	36.2
6	52.6	55.6	48.5	41.3	42.0	48.0
7	12.3	27.5	13.9	9.4	22.3	17.1
No. 1 Bouy	3.6	3.7	7.8	8.1	3.2	5.3
Average (No. 1 - No.7)	42.5	47.5	41.3	33.7	43.1	41.6

Note: No.3 berth is being reconstructed

5) Use of Berths - Before and After the Earthquake

Here, the changes in the use of each berth before and after the earthquake are preliminarily are studied. Before the earthquake, berths No.1 and No.2 were occupied by bulk carriers for handling wheat at a high rate. But these berths were completely destroyed by the earthquake, and their facilities such as sheds, yards, cranes and even the quaywalls themselves all suffered major damages. These berths are therefore completely useless at present. Berth No.3, just under construction, was also damaged by the earthquake. Before the earthquake, berth No.4 was used mainly for container cargoes because of the wide space behind it (about 100 m).

General cargoes and copper were handled at berth No.5, and fruits and fertilizer at berth No.6. Berth No.7 was for domestic trade, handling salt. Berths No.6 and No.7 also suffered considerable damages.

Due to the earthquake damage, the existing port facilities are, of necessity, being used more efficiently than before, and all the cargoes now concentrate on the wharf where the available berths No.4 and No.5 are located. It can be said that the useful berths are No.4, No.5, No.6 and No.7, and that the total berth length of the port has been reduced to about 700 m. Of these berths, loading weights are limited on berths No.6 and No.7.

From the facts mentioned above, there are some problems, as follows:

(a) There is no suitable berth for large-size vessels.

(b) The clean cargoes are handled together with the dirty cargoes (mainly copper).

(c) The flow of cargoes on wharves is congested.

As one of the solutions to these problems, a dolphin type berth for wheat is being constructed at the northern part of the port. However, after the wheat berth is constructed, the problem that concentrated copper (powdered copper) is handled together with clean cargoes (especially fruits and sugar) will still remain.

To solve this, it will be necessary to provide a new wharf for concentrated copper far from the existing wharf at an early stage .

Table III-2-26 shows the performance of cargo handling at the Port of San Antonio in 1984.

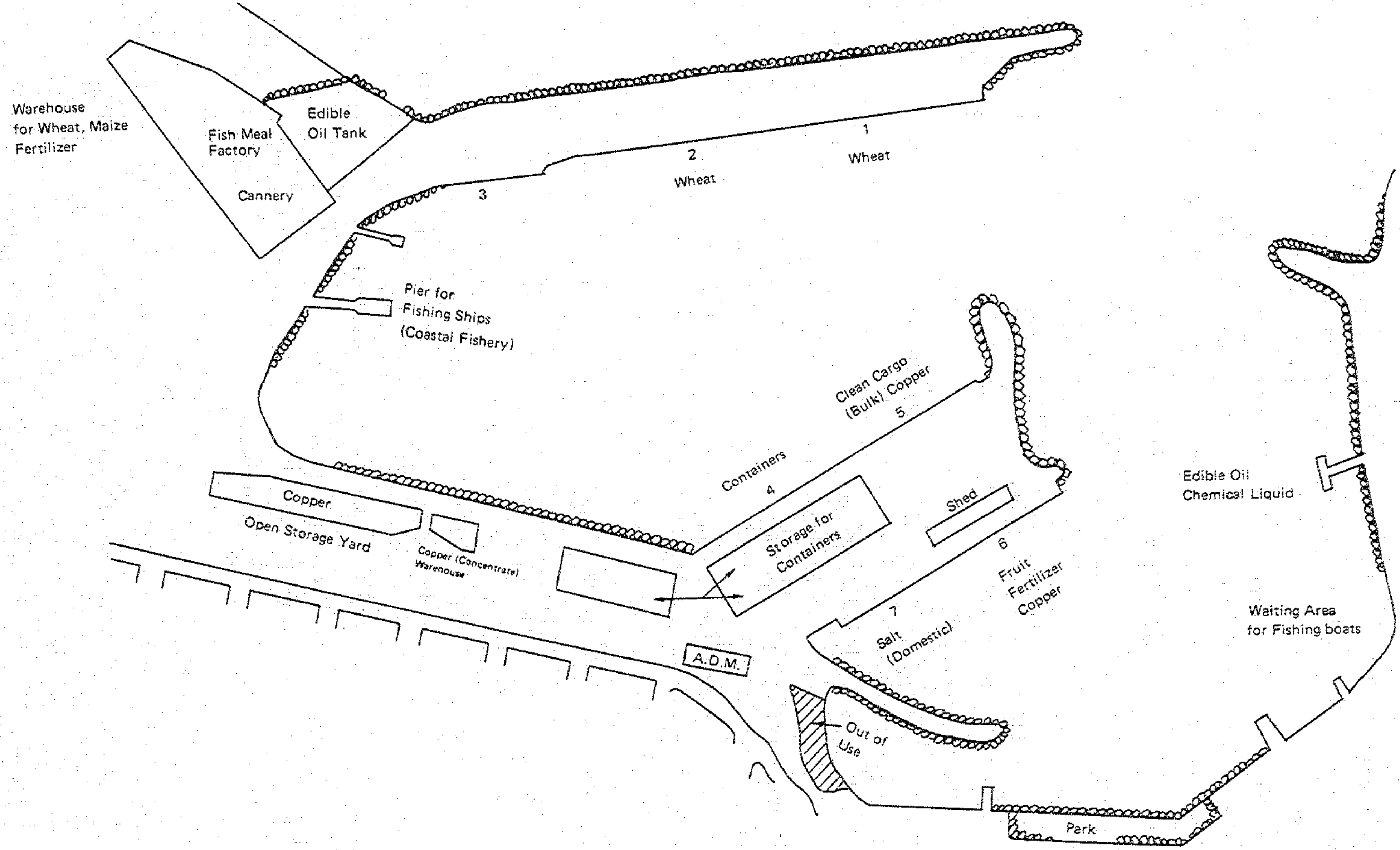


Fig. III-2-7 The Uses of Port Facilities before the Earthquake

Table III-2-26 Performance of Cargo Handling at San Antonio Port in 1984

Berth	Quay Length(m)	Volume of Cargoes Handled (tons)	Composition Ratio (%)	Cargo Handling Volume per Metre (tons/m)	Berth Occupancy Ratio (%)	Main Commodities
1	452	730,552	31.2	3,055	66.3	wheat, copper
2		650,461	27.8		58.7	wheat, copper, chemical products
3	200	-	-	-	-	-
4	383	313,682	13.4	1,609	33.0	copper
5		302,604	12.9		36.1	copper, agricultural products
6	200	276,386	11.8	1,382	42.0	copper, food products, fruits
7	120	46,583	2.0	388	22.3	mineral products, food products
Buoy 1		21,300	0.9		3.2	
	[1,355] 1,155*	2,341,568	100	2,027	[43.1]** 37.4	

* Except the length of berth No.3
** Except the Buoy berth

III-3 Damages to Port Facilities

(1) Outline of Port Facilities

1) The Port of Valparaiso

The Bay of Valparaiso is located on the lee side of Punta Angeles and is well sheltered naturally except from northerly and northwesterly winds and waves. A breakwater is provided extending from Punta Duprat 250 m eastward and then 700 m southeastward. The breakwater is constructed with concrete caisson or concrete block units founded upon a rock mound extending offshore up to water depth of approx. 45 m.

The berthing facilities were constructed between 1915 and 1932 without considering seismic resistance. The aging or deterioration of structural members of the berthing facilities is notable as the facilities are over 50 years old. The berths are mostly constructed as gravity type quaywalls using precast concrete elements (berths 1 to 6 and 8) and precast concrete caisson (berth 7). Baron pier is built with reinforced concrete slab and beam upon concrete piles 4.0 m in diameter. Concrete pile foundations are also adopted in front of the gravity type quaywall of berth 4 to sustain the seaside crane railing.

Fig. III-3-1 shows the original section profiles of these facilities. To better understand the damages caused by the last earthquake on 3/3/85, it may be recalled that the quaywalls at the port of Valparaiso were also damaged by the earthquake in 1971,[1] disturbing normal port operations for many month. In particular, it is reported that the tilting of quaywalls No. 4 and 5 with a maximum displacement of 5 cm and subsidence of the backfill up to 40 cm were prominent. Other damages to quaywalls No. 6 and 7 were also observed with displacement up to 30 cm.

2) The Port of San Antonio

Some berths at the port of San Antonio (berths 3, 4, 5 and parts of 6 and 7) were recently rehabilitated. However, the aging or deterioration of the structural members of berthing facilities is considerable at berths 4, 6 and 7 in particular. Moreover, damages to berths 1 and 2 by the 3/3/85 earthquake have inevitably led to the closing of the berths up to the present.

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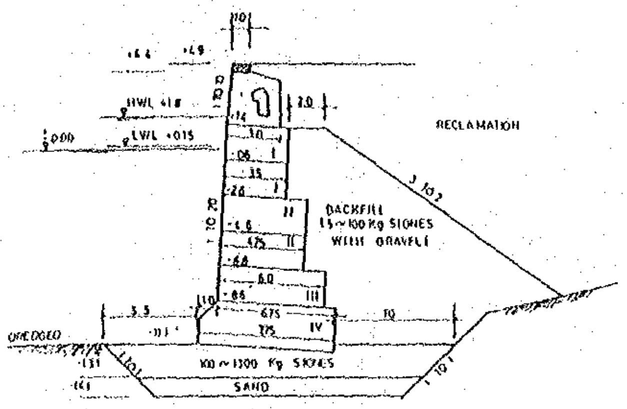
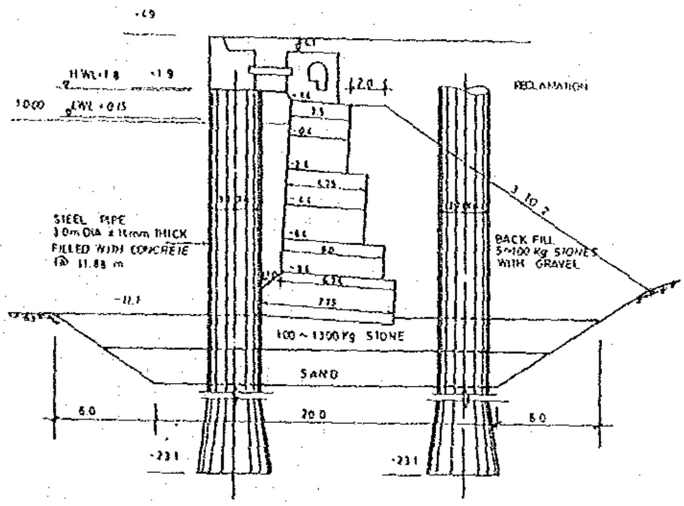
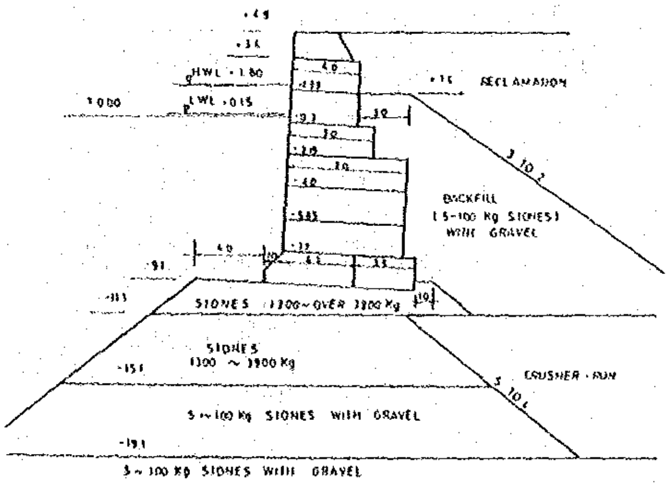
1) Source: R.M. Lastrico and J. Monge, Engineering Aspects of the July 8, 1971 Earthquake in Central Chile



Berth Nos. 1, 2, 3 and 5 (Valparaiso)

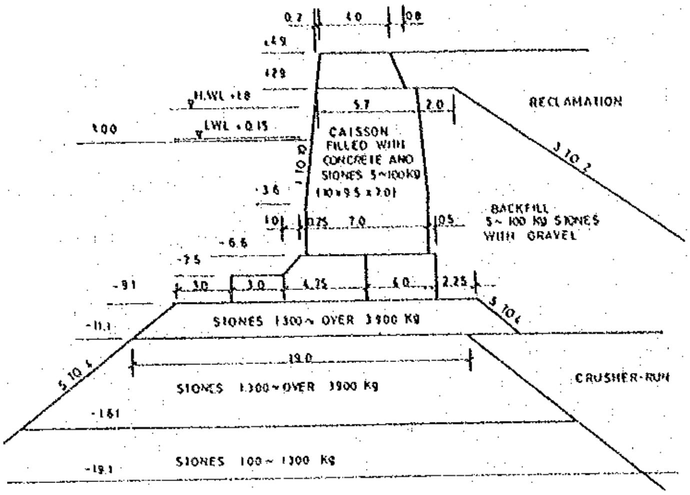


Berth No. 6 (Valparaiso)

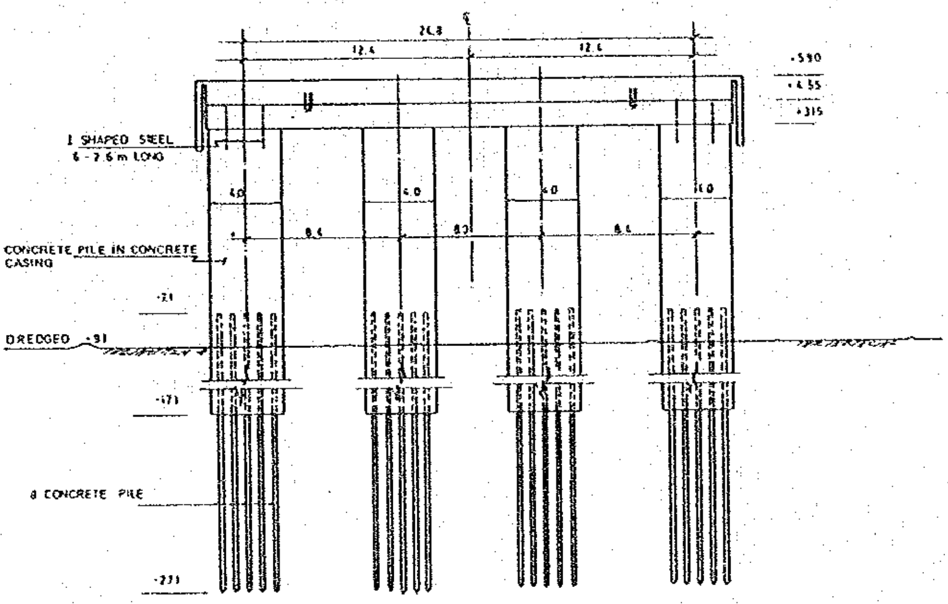


Berth Nos. 6 and 8 (Valparaiso)

Fig. III-3-1 (1) Original Section of Berths at the Port of Valparaiso



Berth No. 7 (Valparaiso)



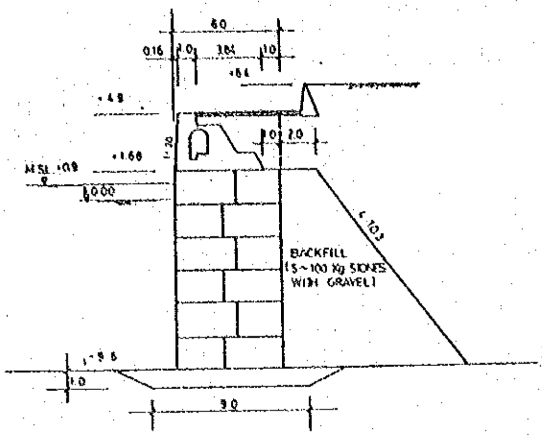
Berth Nos. 9 and 10 (Baron Pier Valparaiso)

Fig. III-3-1 (2) Original Section of Berths at the Port of Valparaiso

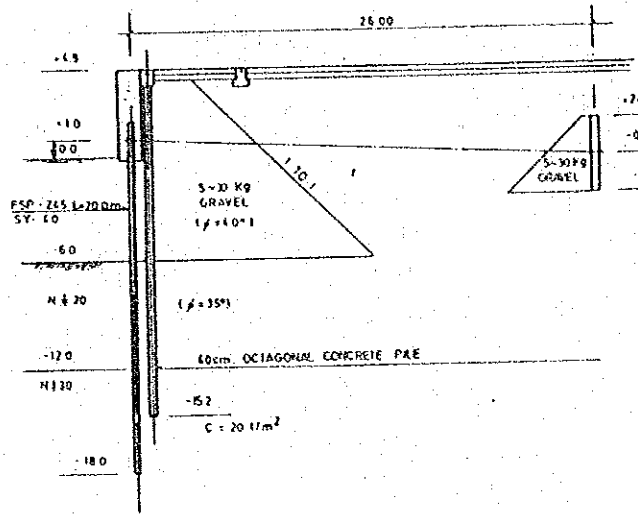
Unlike the port of Valparaiso, the berthing facilities at the port of San Antonio are varied with gravity type quaywalls at berths 1 and 2, steel sheet pile walls at berths 3 and 4 and open type piers at berths 5 to 7. Fig. III-2-2 shows original section profiles of these facilities.

Berthing facilities at the port of San Antonio also suffered damages from the earthquake in 1971.[1)] It is reported that quaywalls 1 and 2 suffered heavy tilting seawards with a maximum displacement of over 60 cm and subsidence at the backfilled yard and apron up to 60 cm. Longitudinal cracks in the yard behind berths 1 to 3 were also observed. Warehouses were heavily damaged and had to be demolished. A group of undamaged steel silos were disassembled for safety purposes. Utilization of berths 1 and 2 had to be suspended for many months after the earthquake took place.

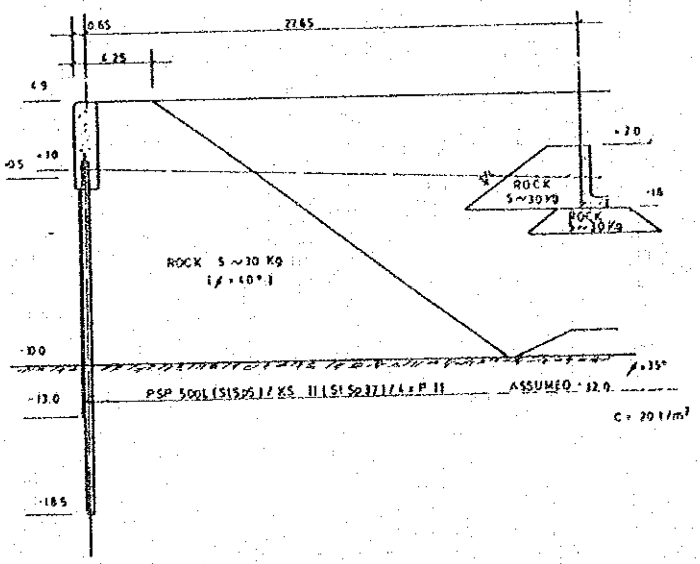
1) Source: See III-3-(1)-1)



Berth Nos. 1 and 2 (San Antonio)



Berth No. 3 (San Antonio)



Berth No. 4 (San Antonio)

Fig. III-3-2 (1) Original Section of Berths at the Port of San Antonio

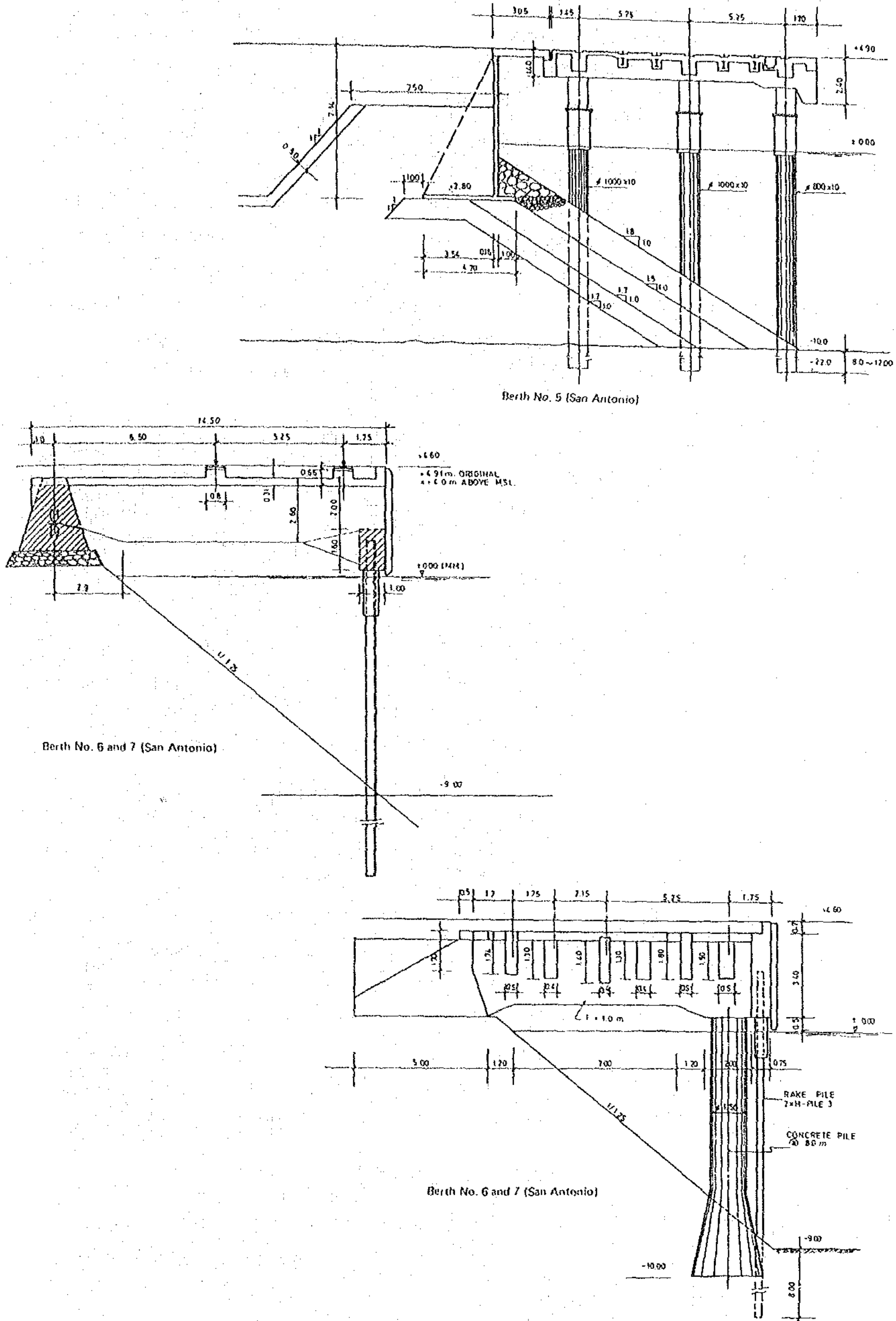


Fig. III-3-2 (2) Original Section of Berths at the Port of San Antonio

(2) Damages to Port Facilities

1) The Port of Valparaiso

(i) Damages to Berthing Facilities

The damages to the berthing facilities and adjacent yards are heavier than the damages to the buildings.

The deformation of quaywalls mostly caused by horizontal sliding towards the harbour varies by berth: less damage at berth 1 to 3 and heavier damage at berths 4 to 8, though more or less in a decimeter scale. The deformations are clearer in the submerged portions of the quaywalls. Another typical pattern of damages to quaywalls is displacement to the harbor side by rotation as observed at berths 5 and 7.

The alignment of crane railings and the railway tracks is still in a state of deformation or settlement, although these facilities have already been partially restored. Settlement is observed showing a wide gap on the paved surface.

The copeline deformations are clear at berths 4, 5, 6, and 8. Berth 5 was tilted slightly seawards by the earthquake in 1971. The present copeline deformation toward the sea measured by our survey is as remarkable as a maximum of 170 cm.

The underwater investigations by divers revealed the following major facts:

① The gap between concrete blocks due to deformation or settlement of quaywalls has been widening and seems more noticeable in obliquely placed concrete blocks at berths 6 and 8,

② Seaward tilting of 1 to 2 degrees of foundation piles exists at berth 4,

③ The cylindrical concrete pile foundation of Baron pier is composed of core concrete covered by outer precast concrete rings 2.5 meters long. Neither breaks nor cracks in the piles were observed.

④ Scouring of the base mound in front of the quaywall caissons at berth 7 and a slight tilting of the caissons towards the harbour side were observed. Thus, the quaywall is unstable.

It is also observed that the aging or deterioration of structural members of berthing facilities has progressed. In particular, the deterioration to concrete and steel bars in the longitudinal beams is remarkable and appears dangerous. This type of deterioration is also found at the bottom face of the seaside crane beam at Berth 4, although the damage there is not so serious.

The overall area of the berths 6 to 8 (Espigon de Atrque) has settled considerably. The copeline heights of these berths are getting lower towards the offshore side. The present copeline height at berth 7 is about 4.3 m above the port datum, which is 60 cm lower than the original height. This may have been caused by a long period of settlement at the base mound and the consolidation of subsoils. It is considered that the settlement there has almost completed.

The extent of damages is summarized in Table III-3-1.

(ii) Damages to Wharf Cranes and Others

Since most of wharf cranes damaged by the 3/3/85 earthquake had already been repaired by the time of our survey, the facts discussed below are based on the report "Damage to Port Facilities in the Port of Valparaiso by the earthquake on March, 3 1985" dated April 2, 1985 by the Japanese Expert Mission.

The extent of damages to wharf cranes at berths 6 to 8 was more severe than at berths 1 to 3. Nearly half of the wharf cranes were damaged at the portal leg and ring. This type of damage was caused by buckling due to over-compression or deformation from being striked by handling cargo. In addition, derailing of land-side wheels and buckling of land-side truck frames were also observed at most of the wharf cranes at berths 6 to 8. No damage occured to the Hitachi crane at berth 4 or to the cranes at berths 9 and 10, but wharf crane No. 26 at berth 7 collapsed.

At present, there is a slight difficulty in movement due to rail deformation at berths 1 to 3 as well as at 9 and 10. Due to a considerable degree of rail deformation, wharf cranes at berths 4 to 8 are difficult or impossible to use for normal cargo handling

Table III-3-1 Extent of Damages and Deterioration to Berths at Valparaiso

	Description	Berth						
		1 to 3	4	5	6	7	8	9 and 10
Damages by the earthquake	Copeline Deformation Seawards	Not remarkable: less than 10 cm	Slight 4 cm	170 cm Max.	74 cm Max.	Max. 20 cm	Max. 60 cm	Negligible
	Horizontal Sliding of quaywall units	10~15cm Max. but 70cm at the connection with berth 4	70 cm Max.	Slight	Heavy sliding partly at the offshore end	Slight	Heavy sliding throughout	-
	Rotation of quaywall seawards	Negligible	None	Remarkable	Negligible	1 - 2°	Negligible	-
	Gap between quaywall elements	Observed but minimal	10 - 20 cm max.	Observed but minimal	Parts remarkable	30 cm at the end units	Remarkable	-
	Scouring of Base Mound	None	None	None	Not cleary observed	Observed near the toe of the caisson	Not clearly observed	-
	Settlement of Apron and back-of-port Area	less than 15cm but 30cm partly at Berth 4	Heavy 35 cm	Heavy 35 cm	20 cm	Heavy 40 cm	Heavy 30 cm	None
	Settlement of Railing	Slight at Berths 1 and 2, but max. 10 cm at berth 3	10 cm Max.	Heavy	3 - 5 cm but 18 cm Max.	Heavy	Heavy 20 cm	None
	Assessment of overall damages	I	III	III	II	III	III	O
Deterioration	Steel materials	-	Progressing	-	-	-	-	Severe in steel bars for beams
	Concrete materials	Progressing	Progressing	Progressing	Progressing	Minimal	Progressing	Severe; dangerous
	Long term Settlement	None	None	None	60cm Max.	60 cm	60 cm Max.	None

Legend: Assessment of overall damage

O: no damage　　II: medium　　IV: Great

I: slight　　III: severe　　-: not applicable operations.

The warehouses at berths 1 to 3 suffered minor cracks in the interior walls. Several cracks running parallel to the copeline of the berths were also observed in the pavement inside the warehouses. Minor cracks in the columns and walls of the warehouses at berths 6 and 8 have also apparently developed. It is uncertain whether these cracks resulted from the 3/3/85 earthquake or from the long-term settlement of the area.

2) The Port of San Antonio

(i) Damages to Berthing Facilities

The damages to the berthing facilities at San Antonio are much heavier than the damages at Valparaiso. The virtual destruction of quaywalls and the severe subsidence of the aprons of berths 1 and 2 are most remarkable. Several wharf cranes collapsed or were damaged in part. Apart from berths 1 and 2, other berthing facilities were all damaged more or less equally, and overall, the port cargo handling operations were considerably restricted as a result of the 3/3/85 earthquake.

① Berths 1 and 2

The gravity type quaywalls completely fell down into the sea or were considerably tilted towards the sea. The apron surfaces were also heavily deformed. The front slope of the utterly destroyed portion is protected by stones from scouring by wave action.

② Berth 3

The horizontally anchored sheet pile wall was tilted towards the harbour on a scale of 70 - 100 cm. This deformation of the quaywall resulted in a considerable opening between the rear face of the coping and the apron pavement. Most of the adjacent paved areas suffered heavy settlement.

③ Berth 4

No significant damages to the steel sheet pile wall took place except for a slight deformation of the copeline seaward and heavy settlement behind the quaywall. However, several holes or openings exist in the submerged portion of the steel sheet piles. Disconnections along the sheet pile jointings were also observed. The damaged portion of the sheet piles was repaired by installing additional piles immediately behind the walls.

④ Berth 5

The L-shaped retaining wall settled and tilted, with settlement of as much as 40 cm at the area behind the deck. It appears that the deck structure and the foundation piles have suffered no damage at all.

⑤ Berth 6 and 7

The rear cope of the deck structure settled about 60 cm.
The concrete foundation piles tilt over toward the harbour with some breakage at the corner of the pile top. Severe corrosion to the welded H-shaped steel piles is about to take place.

The extent of damages and deterioration to berthing facilities is summarized in Table III-3-2.

(ii) Damages to Wharf Cranes and Others

The damages to wharf cranes at berths 1 and 2 were quite heavy. All seven of these wharf cranes collapsed or inclined severely, together with the collapse of the wharf structures. However, there is no damage to the wharf cranes or difficulty in travelling at berth 5. At berths 6 and 7, no damages to the wharf cranes are reported although there is apparently a slight difficulty for the wharf cranes to travel due to rail deformation.
Several cracks in the pavement of the warehouse at berth 2 were brought about by the settlement of the berth yard. The steel-framed warehouse also suffered damages caused by the destruction of the wharf cranes.

Table III-3-2 The Extent of Damages and Deterioration to Berths at San Antonio

Description		Berth No.				
		1 and 2	3	4	5	6 and 7
Damages due to earthquake	Deformation of Copeline toward the harbour	Destroyed	70cm - 100cm	10 - 15 cm	Negligible	Likely to occur
	Settlement of apron and back-of-port yard	Great	Severe	Slight	40cm at back-of-deck area	60cm at the rear end of deck
	Settlement of railings	Great	Heavy	Slight	Nil	Negligible
	Horizontal sliding and tilting of block seaward	Collapse	-	-	Slight	-
	Gap between concrete blocks	Collapse	-	-	Nil	-
	Assessment of Overall Damages	IV	III	I	II	IV
Deterioration of Materials	Steel Materials	-	Nil	Considerable	Nil	Severe; dangerous
	Concrete Materials	-	Nil	Nil	Nil	Severe

Legend: Assessment of overall damages
O: Nil
I: Slight
II: Medium
III: Severe
IV: Great

(3) The Earthquake on March 3, 1985

1) Outline of the Earthquake

The earthquake which took place on March 3, 1985 was the largest in the central region of Chile since 1906. The earthquake had a surface wave magnitude of Ms = 7.8. An isoseismal map with the earthquake intensity at several locations is attached as Fig. III-3-3. The earthquake intensity was VII to VIII at Valparaiso and VIII at San Antonio on the Modified Mercari Scale. The location of the epicenter was about 40 km east from the port of San Antonio and the focal depth was 15 - 30 km.

A comparatively large number of strong earthquake vibrations were recorded during the earthquake. The acceleration seismograms obtained during the earthquake indicate that the maximum horizontal accelerations were 0.293g at Valparaiso and 0.669g at Llolleo near San Antonio. The seismograms were obtained using an SMA-1 type strong motion accelerograph.

The main thrust of the earthquake on March 3, 1985 was composed at least of two shocks. The initial motion started at 22:46:56.4 followed by a larger motion at 22:47:06.9 (Greenwich Mean Time). The magnitude (Mb: body wave magnitude) of the first and second motions were 5.2 and 6.9. As a result, the composite motion produced a surface wave magnitude (Ms) of 7.8. The hypocenter parameters of the main shocks are shown in Table III-3-3.

Table III-3-3 Hypocenter Parameters of the Main Shocks of the Earthquake on March 3, 1985

Origin time	Latitude	Longitude	Depth km	m_b	M_s	Source
22:46:56.4	33.118° S.	71.822° W.	33 N.	5.2	—	NEIS (PDE No. 9-85, March 21, 1985).
22:47:06.9	33.155° S.	71.980° W.	33 N.	6.9	7.5	"
22:46:56.9	33.24° S.	71.86° W.	16			Univ. of Chile, Dept. of Geophysics (E. Kausel, oral commun., 1985) (only initial shock located).

Source: S.T. Algermissen and Others, Site Response associated with the Central Chile Earthquake of March 3, 1985 and Aftershocks

The shocks were preceded by the foreshock sequence. The foreshock activities continued from December 4, 1984 to March 3, 1985. The foreshock activities included a period of quiescence from January 26 through February 20 and greatly increased activities from February 21 through 27 followed by the main shocks on March 3.

The main shocks on March 3 were followed by a series of aftershock activities. Fig. III-3-4 shows the epicenter distribution of the aftershock activities recorded from March 3 through June 17, 1985. The notable shock in the sequence of the aftershocks occured on April 9, 1985 which was Ms = 7.2. The aftershock zone was about 200 km long in the north to south direction and 100 km wide in the east to west direction along the dip of the subduction of the Nazca plate. Fig. III-3-5 shows the focal area of the earthquake on March 3, 1985 in which both cities of Valparaiso and San Antonio are situate.

Minor scale tsunami brought about by the March 3, 1985 earthquake were observed at several ports. The maximum recorded wave heights of these tsunami are summarized in Table III-3-4.

No observation of soil liquefaction was reported in the port area of Valparaiso. At San Antonio, small scale sand boils associated with soil liquefaction were observed at some places in the port yard behind berth No.3.

Table III-3-4 Height of Tsunami

Location	Wave Height (m)	Remarks
Valparaiso	0.2	22:50 GMT
Valparaiso	1.5	00:30
Coquimbo	0.55	03:46
Talcahuano	1.82	03:00
Arica	0.50	04:20
Iquique, Antofagasta and Caldera	0.30	
Quintay	2	estimation by Instituto Hirografico de la Armada
Algarrobo	1.5	estimation by Instituto Hirografico de la Armada
Cartagena	2 - 3	estimation by Instituto Hirografico de la Armada
San Antonio	3 - 4	estimation by Instituto Hirografico de la Armada

Source: E. Kausel V, Process Sismico, Parametros Focales y Replicas del sismo del 3 de Marzo, 1985

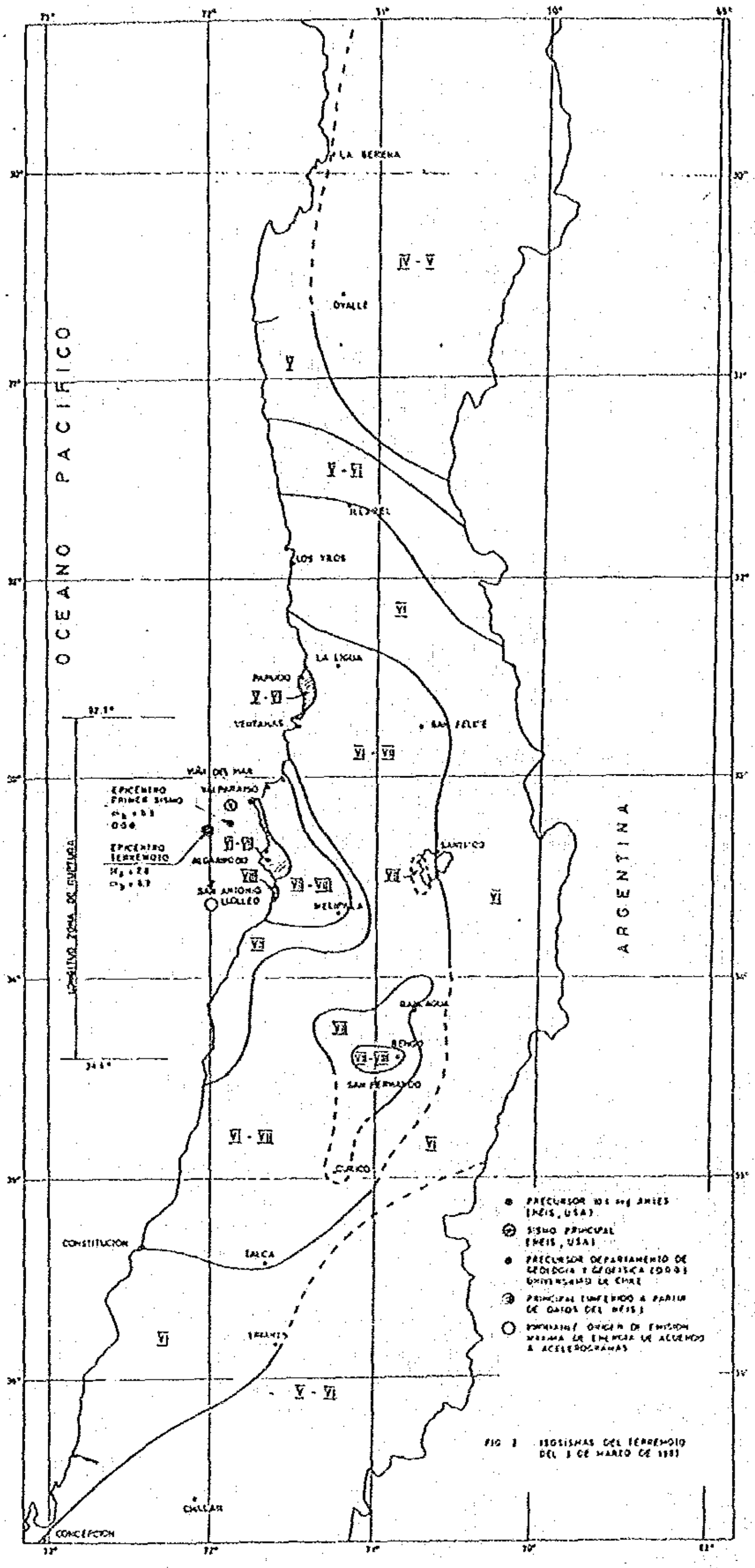
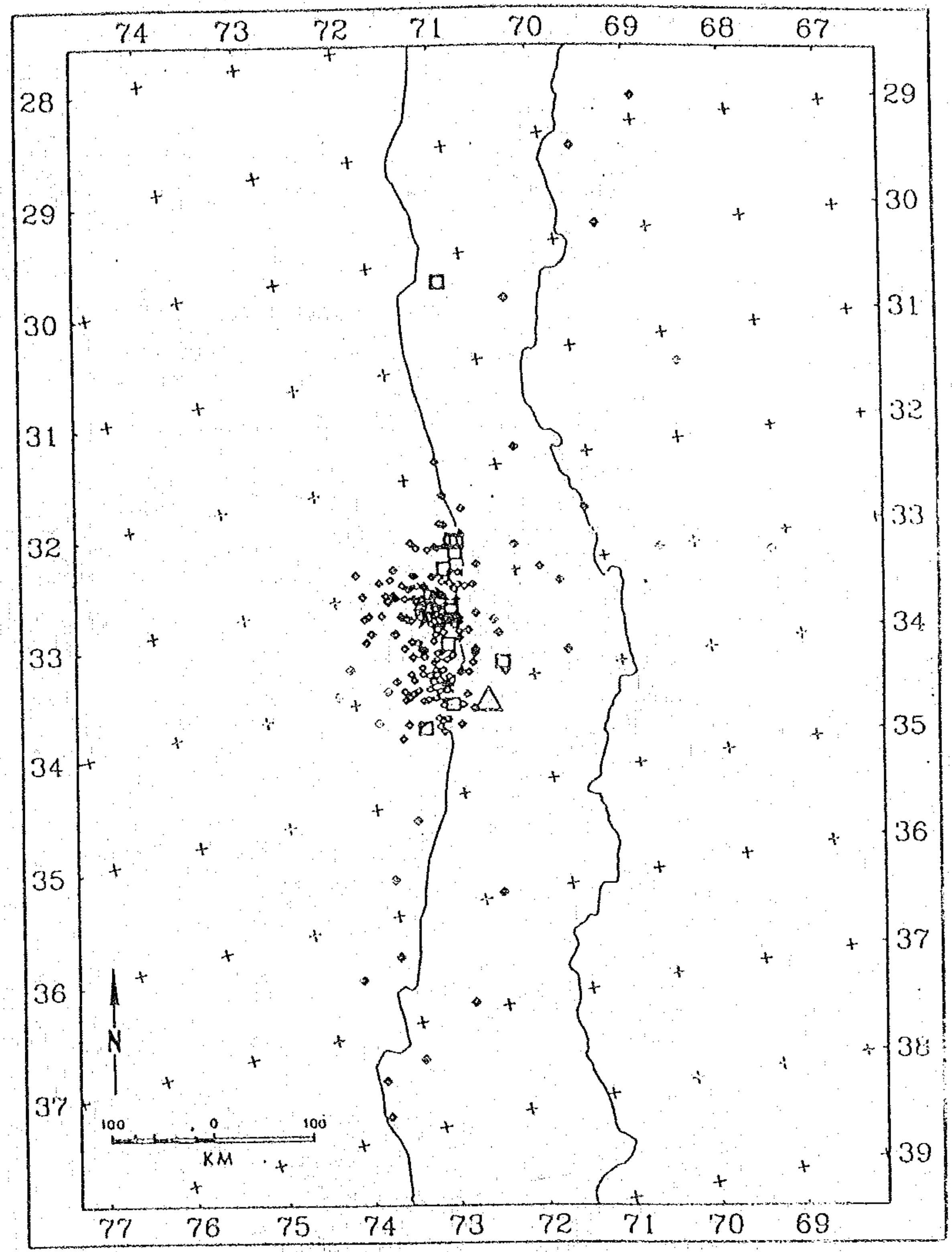


Fig. III-3-3 Isointensity Map of the Earthquake on March,3, 1985

Source: R. Saragoni H., P. González S., M. Fresard B; Analisis de los Acelerogramas del Terremoto del 3 de Marzo, 1985



Legend: The diamonds represent earthquakes $m_b < 6.0$; the squares represent earthquakes $6.0 \leq m_b < 7.0$; the triangle is the M = 7.2 aftershock of April 9, 1985; and the star represents the main shock.

Fig. III-3-4 Epicenter Distribution of Aftershocks from March 3 to June 17, 1985

Source: S.T. Algermissen and others; Site response associated with the Central Chile Earthquake of March 3, 1985 and Aftershocks

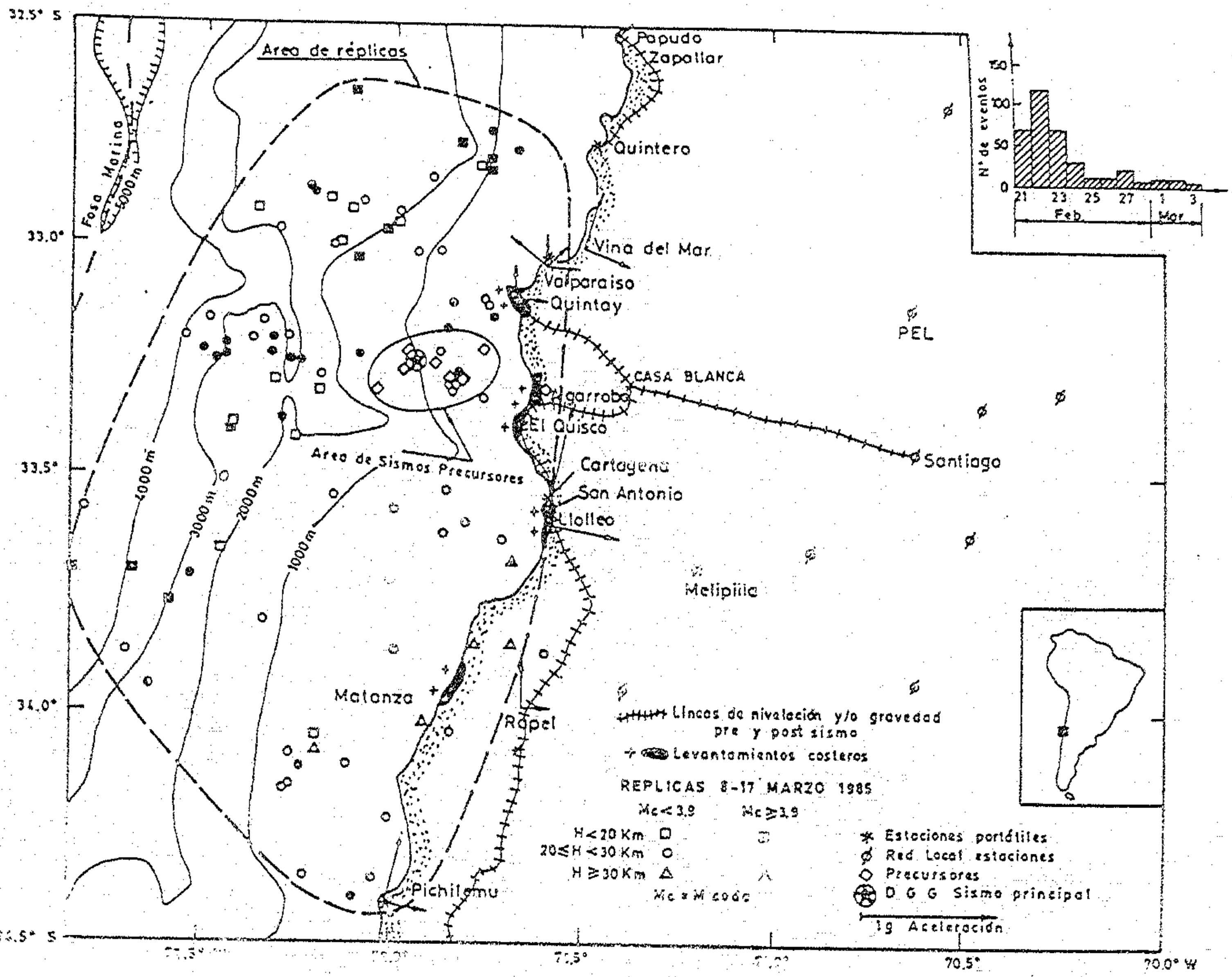


Fig. III-3-5 Focal Area of the Earthquake on March 3, 1985

Source: E. Kausel V; Process Sismico, Parametros Focales y Replicas del Sismo del 3 de Marzo, 1985

(4) Unique Characteristics of the Earthquake on March 3, 1985

1) Long Duration and Long Period Vibrations

The extent of the damages may have been intensified by the long duration of the strong motions. Duration is generally related to the intensity of earthquake vibrations. It seems that the duration of the strong motions at Valparaiso and at Llolleo near San Antonio was about 20 sec as computed by the following formula by Trifunac - Brady (1975).

$$
\begin{aligned}
Ts &= -4.88S + 2.33M + 0.149 \times D \\
&= -4.88 + 2.33 \times 7.8 + 0.149 \times 40 \\
&= 19 \text{ sec}
\end{aligned}
$$

Such port facilities as gravity type quaywalls and sheet pile walls have a short natural period and large dumping, and therefore in the design practice currently adopted, these are designed by static analysis based on the seismic coefficient method. Such dynamic effects of earthquake vibrations as frequency, amplitude and duration, etc. are generally considered as having a minimal affect on the stability of these rigid structures.

However, flexible structures having small damping such as tall buildings and open type piers are significantly affected by these dynamic components of earthquake vibrations. In general, these dynamic components are positively included in the engineering analysis.

In static analysis by seismic coefficient methods, it is generally considered that the effects of these dynamic components of earthquake motions are included in the seismic coefficient which is determined through many earthquake experiences.

2) Strong Motions

The strong motion seismograms of the last earthquake and the results of our dynamic soil response analysis at both ports (referred to subsection III-4) are summarized in Table III-3-5. The base rock as well as the surface ground acceleration at San Antonio are substantially larger than those at Valparaiso. The ratio of the maximum ground acceleration recorded is 0.669G/0.293G = 3.3.

Table III-3-5 Strong Motion Data at Valparaiso and San Antonio

Strong motion seismograms recorded by SMA-1 seismograph			The results of earthquake response analysis				
Location		Acceleration	Location (Br. No.)	Max. Acceleration*		Dominant Frequency	
				Base Rock	Ground	Initial	Convergence
Valparaiso	UFSM	0.179G	2	164 gal	238 gal	2.5	1.2
			4		334	2.8	2.1
	Almondral	0.293G	5		313	2.9	2.1
Llolleo		0.669G	1	513	435	2.7	1.1
			2		427	2.7	1.1
Near San Antonio			3		629	2.6	1.6

* Based on SMAC-B2 type seismograph

The peak acceleration generally appears in shorter periods of strong motions on the accelerations response spectra as shown in Fig. III-3-6(1). Since such port structures as gravity quaywalls have a natural period (T) of more than 1.0 sec. and damping ratio (h) of 0.05, the peak accelerations of short periods do have not much affect on the stability of the structures.

Based on Fig. III-3-6(1), the ratio of accelerations for T = 1.0 sec. and h = 0.05 at Valparaiso an Llolleo is 0.65G/0.65G = 1.0. Fig. III-3-6(2) shows the velocity response spectra at both locations, the ratio of which (T = 1.0 sec. and h = 0.05) is 105/95 = 1.1.

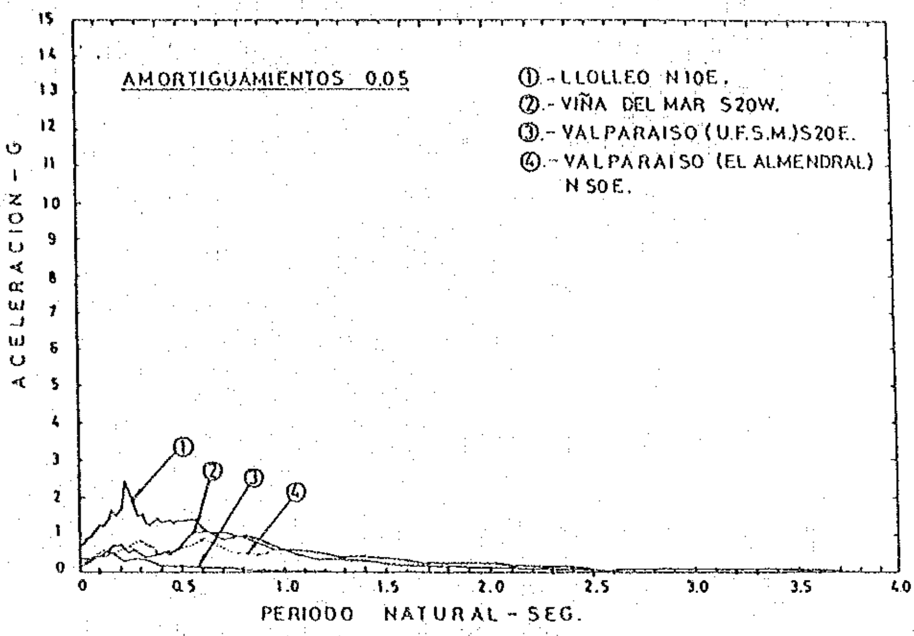
The acceleration at the natural period of the structures represents the acceleration response of the structure which is proportional to the force of inertia. The velocity represents the energy of the motions to the structures, which is also one of the decisive factors for the structural stability.

In view of the above, the effects of strong motions of the last earthquake to structures at both ports are not so different: presumably they were about 10% larger at San Antonio than at Valparaiso even though the maximum ground accelerations are quite different.

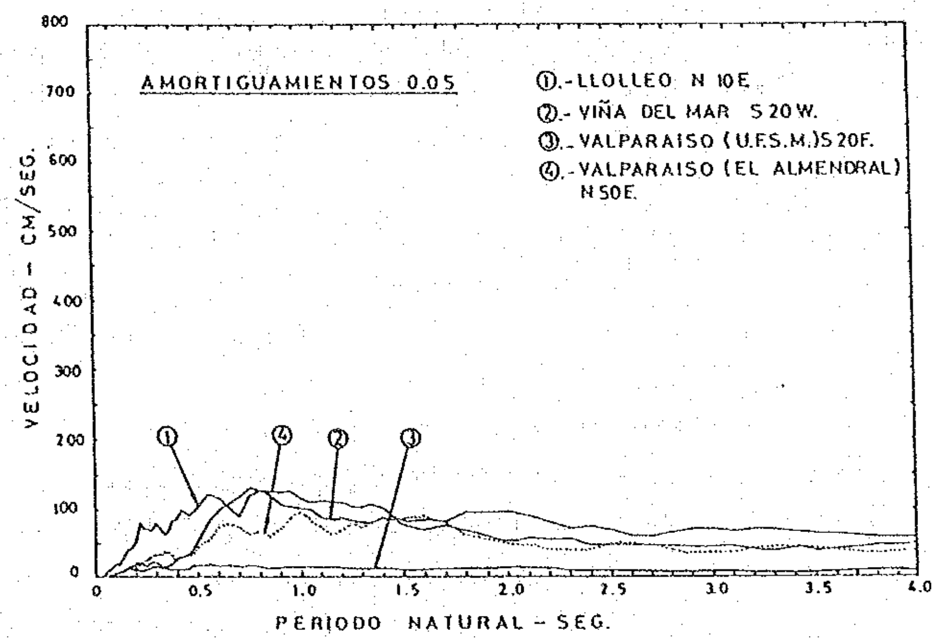
3) Large Aftershocks

The series of the aftershocks which succeeded the main shock on March 3, 1985 are described below.

the largest event	:	M = 7.2 on April 9, 1985
other major events	:	at least nine shocks of $6 < M < 7$ during 3/3/85 to 6/17/85



(1) Acceleration Response Spectra



(2) Velocity Response Spectra

Fig. III-3-6 Strong Motion Spectra of 3/3/85 Earthquake

Source: R. Saragoni H., P. González S., M. Fresard B; Analisis de los Acelerogramas del Terremoto del 3 de Marzo, 1985

The proportion of the energy release by the aftershocks through June 17 is estimated as 36 percent of the energy released by the main shocks.[1] This relatively high ratio of the aftershock energy release is a result of the M = 7.2 aftershock on April 9, 1985.

The aftershock region tends to have a wider distribution as the earthquake magnitude is greater. This trend is given by the following equation:

$$\log L = 0.5\,Mm - 1.8 \qquad 5.5 \leq Mm \leq 8$$

Where L: approx. diameter of aftershock region (Km)

Mm: magnitude of main shock

From the above equation, the aftershock region is estimated as 100 Km in diameter which is notably smaller than the actual one. This may indicate that the energy release by the main shocks was relatively large in the case of the 3/3/85 earthquake.

In general, the total energy release by a series of aftershoks is less than that by the main shocks. The difference between the main shock magnitude (Mm) and the largest aftershock magnitude (M) is generally 0 to 3 and about 1.0 on the average for earthquakes with shallow focal depths. Richter (1985) gave a difference of 1.2 by his Báth's formula. The magnitude of the largest aftershock is estimated at M = 7.8 - 1.0 = 6.8 to M = 7.8 - 1.2 = 6.6, but the actual magnitude was much larger than what was calculated.

The damages to structures by the main shocks may have been intensified by the succeeding aftershocks. Further damages to port facilities by the aftershocks are uncertain due to the lack of information, but it is presumed that remarkable damages were not caused. Almost all the energies of the last earthquake are considered to have been released by the series of aftershocks which continued until June 17, 1985.

4) Widespread Groundshaking

The ports of Valparaiso and San Antonio are situated within the focal region of the 3/3/85 earthquake. The extent of the focal region of an

1) Source: S.T. Algermissen and others, Site Response Associated with the Central Chile Earthquake of March 3, 1985 and Aftershocks

earthquake is closely related to the magnitude of the earthquake, but the maximum acceleration within the focal region of an earthquake is understood to be almost constant for large-scale earthquakes. In various studies, the following maximum limits of the base rock accelerations within the focal region of earthquakes are estimated:

Table III-3-6 Maximum Base Rock Acceleration within Focal Region

Publishers	Max. acceleration (gal)	Remarks
Katsumata (1972)	400 (M ≧ 5)	at the edge of the focal region
Gutenberg-Richter (1956)	180 (M = 7) 450 (M = 8)	log ao = $-2.1+0.81M-0.027M^2$
Okamota (1971)	440 (M = 7) 580 (M = 8)	
Schnabel-Seed (1973)	350 (M = 5.6) 500 (M = 6.6) 300 (M = 6.6)	ℓ = 7 Km ℓ = 10 Km ℓ = 20 Km } based on observations

For this, the acceleration of base rock motions will be a constant value of about 300 - 500 gals maximum. Therefore, it is prudent to consider that maximum base rock accelerations larger than those experienced by the last earthquake would not be caused even if another large earthquake may occur in this region.

On the other hand, the amplification effect by soil layers upon the base rock is important to evaluate the surface ground motions. Our dynamic soil response analysis of the last earthquake vibrations discussed in subsection III-4-(3) evaluates this amplification effect by the soil layers during the strong motions. Generally, the amplification effect by soil layers upon the base rock is significant for weak or moderate motions, but not for strong motions because of its upper limitation of constant values. The amplification effect is largely dependent upon the predominant periods of the soil layers and the response spectra of the strong motions of earthquakes.

5) Large Subduction Earthquake with a Focal Depth of 15 - 30 Km.

The earthquake on March 3, 1985 was the largest subduction earthquake to strike central Chile since 1906. The focal depth of the earthquake was

15 to 30 Km on the interplate subduction with a dip slip angle of 10 degrees. This is deemed most common to the subduction of the Nazca plate.

In general, the shallower the focal depth of an earthquake, the more severe the extent of damages around the source regions. When the faulting of an earthquake reaches the surface ground, the resulting damages become more serious within the limited area near the fault. The length of the earthquake fault is generally about 100 Km in the case of an M = 8 class earthquake.

6) Tsunami

The cause of tsunami is the water mass displacement due to the vertical movements of the sea bed. The source area of tsunami is approximated to be the same as the aftershock region of the earthquake.

Tsunami waves can be estimated from the possible location and parameter of the fault and the sea bed configurations. The prediction of tsunami requires highly specialized knowledge and judgement since it is closely related to such earthquake parameters as magnitude, focal depth, mechanisim of the earth crust fracture and velocity of faulting, etc.

During the last earthquake, the maximum wave height of tsunami observed was 1.15 m at Valparaiso. Although no data is available at San Antonio, the maximum height is estimated at 2 - 3 m by the Instituto Hidrografico de la Armada as presented in Table III-3-4.

The large earthquake which took place in 1906 and destroyed central Chile is reported to have caused minor tsunami of 0.4 - 0.5 m at Concon but no tsunami were observed at Algarrobo, Valparaiso or San Antonio according to Historia Sismica de los Andes Meridionales by F. de Montessus de Ballore. However, the 1960 earthquake which struck southern Chile between Concepción and Aisen is reported to have caused tsunami.

Basically, interplate subduction earthquakes occur through dip-slip faulting and, therefore, have a pronounced tendency to causes tsunami. The periods of tsunami waves are very long and effects of the tsunami waves to port structures are similar to those caused by hydrostatic water pressure. In the case of the tsunami caused by the last earthquake, it appears that the tsunami themselves did not cause any decisive damage to the port facilities.

7) Soil Liquefaction

No significant soil liquefaction during the last earthquake was observed at Valparaiso. However, a minor scale of soil liquefaction was reported behind berth 3 at San Antonio where sand boils were traced in 2 or 3 places. The scale of soil liquefaction observed, however, is not so serious compared with our experiences in Japan.

The technical study on the soil liquefaction in both ports (referred to in subsection III-4) has led us to conclude that there is a large possibility that soil liquefaction occurred at the subsurface backfill soils at berths 1 and 3 (Br. No.1 and 2) when strong motions of not less than 350 gals on base rock struck the port of San Antonio. Since the strong motions base rock at San Antonio were presumed to be more than 350 gals, one of the major causes of damages to the port structures at San Antonio by the last earthquake was the soil liquefaction. This is particularly observed in the case of the damages to berth No. 3.

III-4 Stability Investigation

(1) General

In order to obtain a reliable basis of judgment for the immediate restoration measures, it is necessary to first assess the stability of the existing structures and the possible causes of damages from the last earthquake.

The stability of the existing structures as originally designed is computed based on the static analysis by the seismic coefficient method. A minimum seismic coefficient (Ks min) at which the quaywalls become unstable is clarified through the study.

It is a general principle that the intensity of the ground surface earthquake vibrations varies by location and is governed by the subsoil conditions upon the base rock. In investigating the causes of damages, therefore, it is fundamental to have a better understanding of the dynamic ground motions of the last earthquake. This investigation is carried out by adopting a dynamic soil response analysis during the earthquake. The results are reflected to the investigation on the possibility of soil liquefaction.

The results of the above studies are used to investigate the stability of existing structures and the possible causes of damages. The investigation is carried out based on the Japanese methods of evaluation of the seismic stability of port structures. A method of evaluation to investigate the stability of existing structures for a specific earthquake has already been established in Japan considering the dynamic effects caused by the strong motions as much as possible.

(2) Stability Check by Seismic Coefficient Method

The stability of existing structures as originally designed is computed for different seismic coefficients to show the effects of the seismic vibration intensities on the structural stability. The calculation results under unloaded conditions are summarized in Table III-4-1.

Table III-4-1 Seismic Coefficient for Failure of Existing Structures

Port	Berth No.	Check Elevation (m)	Seismic Coefficient for failure (Ks min) Sliding	Overturning	Remarks
Valparaiso	1, 2	-6.6	0.09	0.11	
	3, 5	-11.1	0.14	0.18	
	4	-6.6	0.09	0.11	Composite with pile foundation of which lateral resistance is omitted
		-11.1	0.14	0.18	
		crane beam foundation	0.17 for lateral resistance of piles		
	6, 8	-7.7	0.12	Over 0.20	
		-9.1	0.17	Over 0.20	
	7	-6.6	0.15	Over 0.20	Caisson Type
		-9.1	0.18	Over 0.20	
	9, 10	Foundation pile	0.19 for lateral resistance of piles		Open Pier
San Antonio	1, 2	-9.6	0.11	0.07	
	3	-	over 0.25		Sliding of anchoring
		-	over 0.25		Sheet pile wall and Tie Rods
	4	-	0.17		Sliding of Anchoring
		-	min. 0.16		Sheet pile walls and Tie Rods
	5	-	0.35		Pier deck foundation
		-	0.17	over 0.25	L-shaped retaining walls
		-	0.12		Slope under pier deck
	6, 7	-	Nil		Concrete Pile
		-	Nil		H-shaped piles
		-	0.10		Slope under pier deck

(3) Dynamic Soil Response Analysis of the Earthquake on March 3, 1985

1) Acceleration Seismograms at Base Rock for Soil Response Analysis

The dynamic soil response during the last earthquake can be investigated by adopting the computer model program SHAKE [1).].

The earthquake waves on the base rock are transmitted through layers of soils to the ground surface where the earthquake waves are perceptible.

1) Source: P.B. Schnabel, J. Lysmer and H.B. Seed, SHAKE-A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites (1970)

Therefore, the earthquake waves on the base rock have to be determined first.

The acceleration seismograms were recorded at Valparaiso and Llolleo near San Antonio by SMA-1 type strong motion accelerographs. In Japan, SMAC-B2 strong motion accelerographs are currently used for the seismographs observation. The sensitivity characteristics of the SMAC-B2 seismographs are quite different from those of the SMA-1 in the high frequency range. Therefore, the acceleration seismograms recorded by the SMA-1 seismograph are first converted into an SMAC-B2 seismograph base so that the study of the dynamic soil response during the earthquake can be carried out on the Japanese basis.

Figs. III-4-1 and III-4-2 show acceleration seismograms simulated from those actually recorded at Valparaiso (USFM N70E on base rock) and Llolleo (N 10E assumed to be the surface ground motion) near San Antonio. The acceleration seismograms represent base rock motions having the same response spectra as those recorded. Table III-4-2 compares the differences of the base rock accelerations between SMA-1 and SMAC-B2 accelerographs. The acceleration on the basis of the SMA-1 accelerograph is about 30% larger than that of the SMAC-B2.

Table III-4-2 Comparison of Acceleration by SMA-1 and SMAC-B2 Accelerographs

Location	Recorded Acceleration	Acceleration on Base Rock (Gals)		$\frac{\alpha \text{ SMA-1}}{\alpha \text{ SMAC-B2}}$
		SMA-1	SMAC-B2	
Valparaiso (UFSM N70E)	0.179 g	211	165	1.28
Llolleo (N10E)	0.669g	706	513	1.38

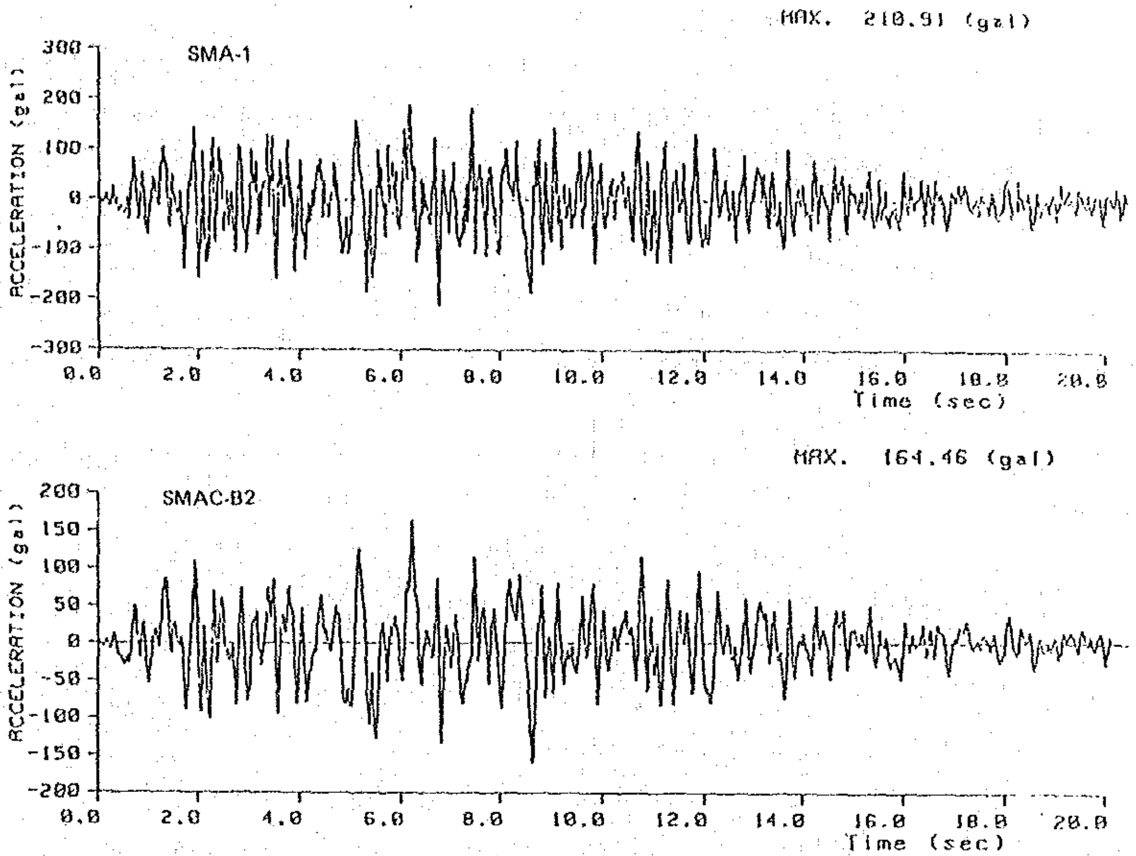


Fig. III-4-1 Acceleration Seismograms at Valparaiso

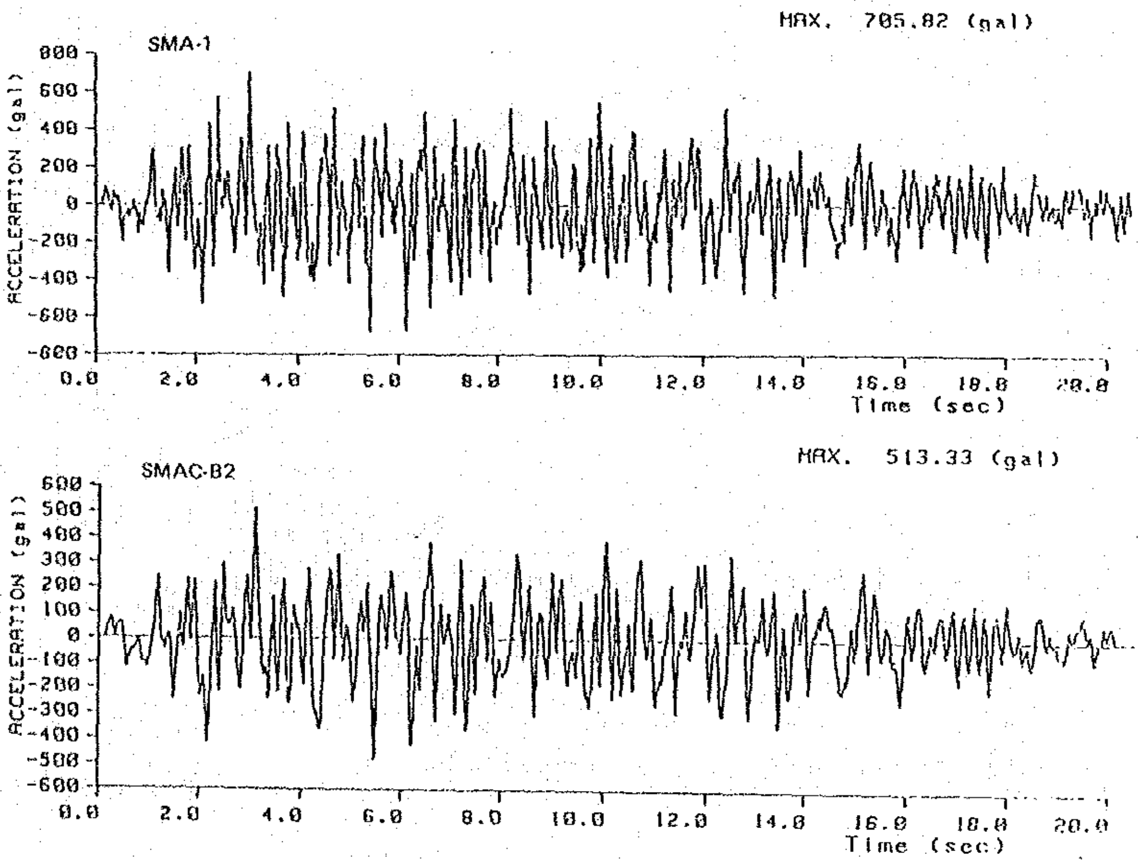


Fig. III-4-2 Acceleration Seismograms at Llolleo Near San Antonio

2) Model of Soil Conditions

The base rock is technically considered as a very hard stratum having a transverse wave velocity of not less than 300 m/s. The soils upon the base rock are divided into horizontally layered soils of 2 - 2.5 m in thickness having the same soil properties such as transverse wave velocity, N-value and uniaxial compressive strength.

The velocity of transverse waves (Vs) and longitudinal waves (Vp) is obtained through our method of PS prospecting which was carried out using 3 bored holes at each port.

3) Dynamic Soil Response

The soil response analysis was carried out at 3 locations in each port as outlined below.

Valparaiso	:	Boring Nos. 2, 4 and 5
San Antonio	:	Boring Nos. 1, 2 and 3

The results of the investigation using computer aids is summarized in Table III-4-3, which is indication of the effects by the earthquake response of subsurface soils and the local configrations of the base rock. The findings are as follows.

① Intial and convergence-predominant frequencies are 2.5 - 2.9 Hz and 1.2 - 2.1 Hz respectively and there is not much difference between Valparaiso and San Antonio.

② Intial amplification rates at Valparaiso are 5.3 to 8.1 while those at San Antonio are 2.4 to 3.0. The same trend is also observed in the amplification rates of acceleration.

③ In the port of Valparaiso, the amplification rates of acceleration are maximum at Br. No. 4 and minimum at Br. No. 2. This difference is due to the soil thickness upon the base rock.

④ In the port of San Antonio, the amplification rates of acceleration increase in the order of Boring Nos. 1-2-3.

Table III-4-3 Results of Soil Response Analysis

Location		Max. Acceleration (gal)		Dominant Frequency (Hz)		Amplification Rate	
Port	Br. No.	On Base Rock	On Ground Surface	Initial	Convergence	Initial	Convergence
Val-paraiso	2	164	238	2.5	1.2	7.5	2.9
	4	164	334	2.8	2.1	8.1	4.4
	5	164	313	2.9	2.1	5.3	3.6
San Antonio	1	513	435	2.7	1.1	3.0	2.2
	2	513	427	2.7	1.1	2.4	1.8
	3	513	629	2.6	1.6	2.4	2.2

Note: Max. accelerations are on the basis of the SMAC-B2 accelerograph.

(4) Possibility of Soil Liquefaction

Soil liquefaction is likely to take place if soils comprising fine-grained and saturated materials of low peameability are loosely deposited. Loose fine sands or coarse silt are most likely to result in soil liquefaction due to the effect of the excessive pore water pressure induced by the seismic vibrations. In general, the soil liquefaction continues until the excessive pore water disappears, forming denser deposits. The possibility of the soil liquefaction is largely related to the degree of density and the grain size distribution of soils.

Seismic vibrations also cause a dynamic shear stress against the effective vertical stress. The dynamic shear stress ratio, i.e., the ratio of dynamic shear stress against the effective vertical stress in the depth of the soil is also a decisive factor for the occurrence of soil liquefaction.

The soil liquefaction results in excessive loading of structures near the liquefied soil-mass. The risk of soil liquefaction, therefore, must be carefully assessed in the stability investigation of the port facilities.

The possibility of soil liquefaction is thus assessed based on the standard methods presented in the design manual for soil liquefaction for port structures compiled by the Bureau of Ports and Harbours, Ministry of Transport of Japan. It includes the following two methods of assessment.

① assessment by the grain sizes and N-values of soils

② assessment by the dynamic shear stress ratio

1) Assessment by Grain Sizes and N-values of the Soil

The results of the assessment by grain sizes and N-values are summarized in Table III-4-4. No possibility of soil liquefaction is obtained at the port of Valparaiso. The result at the port of San Antonio suggests that the soil liquefaction study should be further assessed using the dynamic shear stress method.

Table III-4-4 Assessment of Soil Liquefaction by Grain Sizes and N-values

Port	Br. No.	Thickness of Soil Layer (m)				Overall Assessment
		I	II	III	IV	
Valparaiso	2	-	-	1.8	17.9	○
	4	-	-	-	19.4	○
	5	-	1.15	-	17.55	○
San Antonio	1	-	1.65	3.2	15.05	△
	2	-	-	-	20.55	○
	3	-	-	-	19.95	○

Notes 1) Soil Classifications

I : decisively liquefied

II: probably liquefied, but should be further evaluated using the dynamic shear stress ratio

III: probably not liquefied, but should be further evaluated using the dynamic shear stress ratio

IV: decisively not liquefied

2) Overall Assessment

X: liquefied (soil layers I + II $\geqq$ 2.5m)

O: not liquefied (soil layers I + II + III < 2.5m)

Δ: subject to further assessment using the dynamic shear stress method

2) Assessment by Dynamic Shear Stress Ratio

The assessment by this method is based on the relationship between the number of cycles ($N\ell$) and the cycle stress ratio which is obtained by the cycle triaxial compression test (refer to Section II in this report). In applying the test result, reference was also made to the cycle triaxial compression tests which were carried out at the university of Católica under the order of Direccion de Obras Portuarias, MOP.

The dynamic shear stresses of the soils (L) obtained by our soil response analysis and the cycle stress ratio(R) of the cycle triaxial compression tests are the decisive factors for determining soil liquefaction. The possibility of soil liquefaction is assessed by the safety factor ($F\ell$) as follows.

$$F_{\ell} = \frac{R}{L} \geq 1.0 \ : \ \text{not liquefied}$$
$$F_{\ell} = \frac{R}{L} < 1.0 \ : \ \text{liquefied}$$

The results of the assessment by the dynamic shear stress method are summarized in Table III-4-5. No possibility of soil liquefaction results at the port of Valparaiso where the maximum ground accelerations by the last earthquake are considered to be 240 - 330 gals. At the port of San Antonio, the upper backfill soils at berths 1 and 3 were possibly liquefied during the earthquake vibrations of 430 gals on the ground surface. The study results coincide with the reports on the soil liquefaction occurence at both ports.

But, no evidence of soil liquefaction was reported at boring nos. 1 (berth 1) and 3. At the port of San Antonio, therefore, further study was carried out to compare the possibility of soil liquefaction in different accelerations of 200 and 400 gals base rock motions. The study results indicate that the subsurface backfill soils at berths 1 to 3 having N-value of around 10 may possibly be liquefied by base rock motions of not less than 350 gals.

Table III-4-5 Assessment of Soil Liquefaction by Dynamic Shear Stress Ratio

Acceleration on Base Rock (gal)	Br. No.	Layer No.	Depth of Layer El(m)	Relative Density Dr (%)	Resistance		Working Force		Safety Factor Fl
					Neq	R	L max	L	
The Port of Valparaiso									
164	2	3	+1.3 ∿ -0.5	59.8	5.2	0.577	0.186	0.121	4.77
		4	-0.5 ∿ -1.8	78.9	6.1	0.713	0.158	0.103	6.94
		5	-1.8 ∿ -2.8	82.7	5.1	0.806	0.172	0.112	7.19
		6	-3.8 ∿ -5.6	63.0	5.7	0.587	0.191	0.124	4.72
		7	-5.6 ∿ -7.4	51.1	5.3	0.488	0.194	0.126	3.87
	5	3	+1.8 ∿ +0.4	46.6	15.1	0.282	0.294	0.191	1.48
		4	+0.4 ∿ -1.2	69.2	13.2	0.443	0.298	0.193	2.29
		5	-1.2 ∿ -3.1	84.6	10.4	0.603	0.363	0.236	2.56
		6	-3.1 ∿ -5.1	70.6	9.4	0.528	0.386	0.251	2.10
		7	-5.1 ∿ -6.8	70.2	9.1	0.530	0.394	0.256	2.07
		8	-6.8 ∿ -8.5	89.2	9.0	0.679	0.393	0.255	2.66
The Port of San Antonio									
514	1	3	+1.2 ∿ -0.4	75.9	21.9	0.29	0.453	0.295	0.99
		4	-0.4 ∿ -2.0	71.9	23.0	0.272	0.455	0.295	0.92
		5	-2.0 ∿ -3.7	61.6	25.7	0.227	0.428	0.279	0.81
	2	4	+0.4 ∿ -1.3	77.0	23.3	0.290	0.428	0.278	1.04
		5	-1.3 ∿ -3.0	73.0	23.4	0.275	0.470	0.306	0.90
		6	-3.0 ∿ -4.7	69.5	23.8	0.261	0.490	0.318	0.82
		7	-4.7 ∿ -6.3	66.6	24.3	0.248	0.486	0.316	0.79
	3	3	+0.5 ∿ -0.9	80.3	23.1	0.303	0.589	0.383	0.79
		4	-0.9 ∿ -2.4	89.6	23.6	0.337	0.620	0.403	0.84

(5) Stability Investigation and Possible Causes of Damages

1) Assessment Methods used in Japan

Static analysis by the seismic coefficient method is adopted in the current design practice of port structures in Japan. This method of design is based on the assumption that the static force of inertia of structures corresponding to the seismic coefficient caused by seismic vibrations is the most essential factor for stability during earthquakes. But, the stability of structures are actually more or less affected by the dynamic characteristics of earthquake vibration.

The effects of these dynamic components of earthquake vibrations on port structures have been investigated in Japan. Even in Chile, the investigation results carried out in Japan can serve as a basis to investigate the causes of damages as well as to design aseismic structures. As far as the evaluation of the seismic stability in view of the dynamic effects of ground vibrations is concerned, the studies in Japan are considered among the most reliable because of the many earthquakes which occur in Japan.

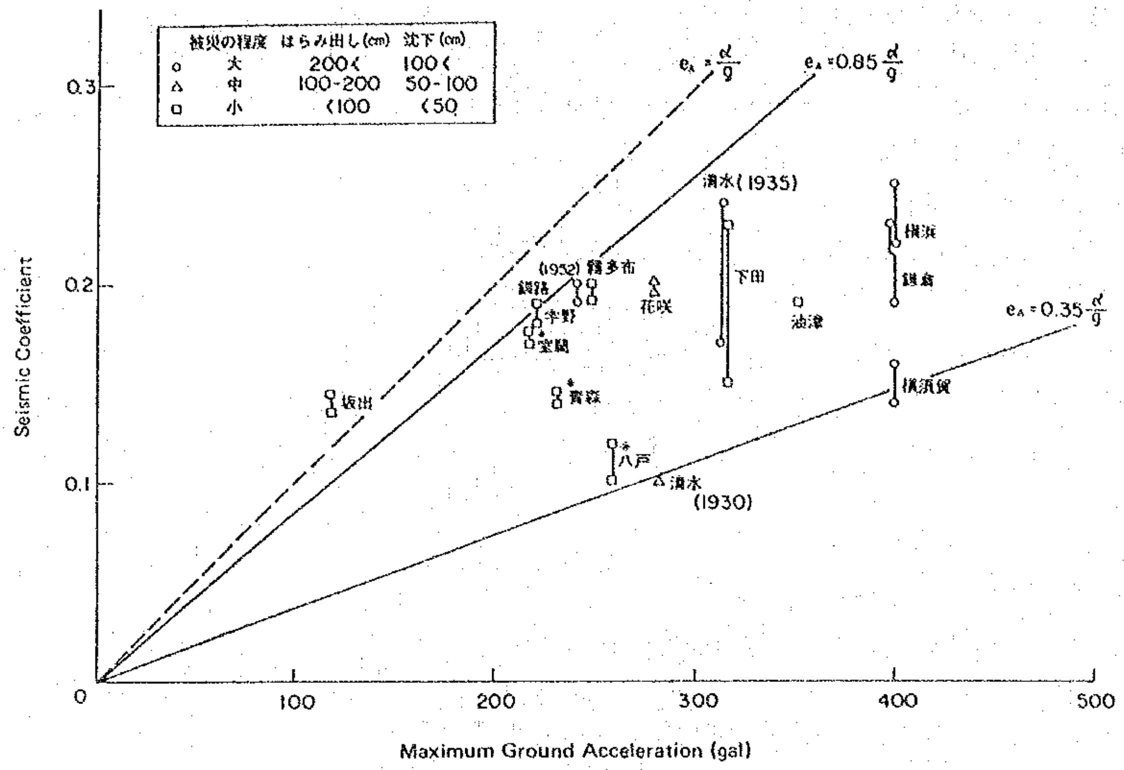
In applying the study results to Chile, it must be considered that the instrument for the strong motion observation is an SMAC-B2 type accelerograph in Japan while the SMA-1 type is used in Chile, and the sensitivity of these instruments is very different in the high frequency range. It is estimated that the base rock acceleration measured by the SMA-1 accelerograph used in Chile is about 30% larger than that measured by the measured by the SMAC-B2 used in Japan.

(i) Rigid Type Structures

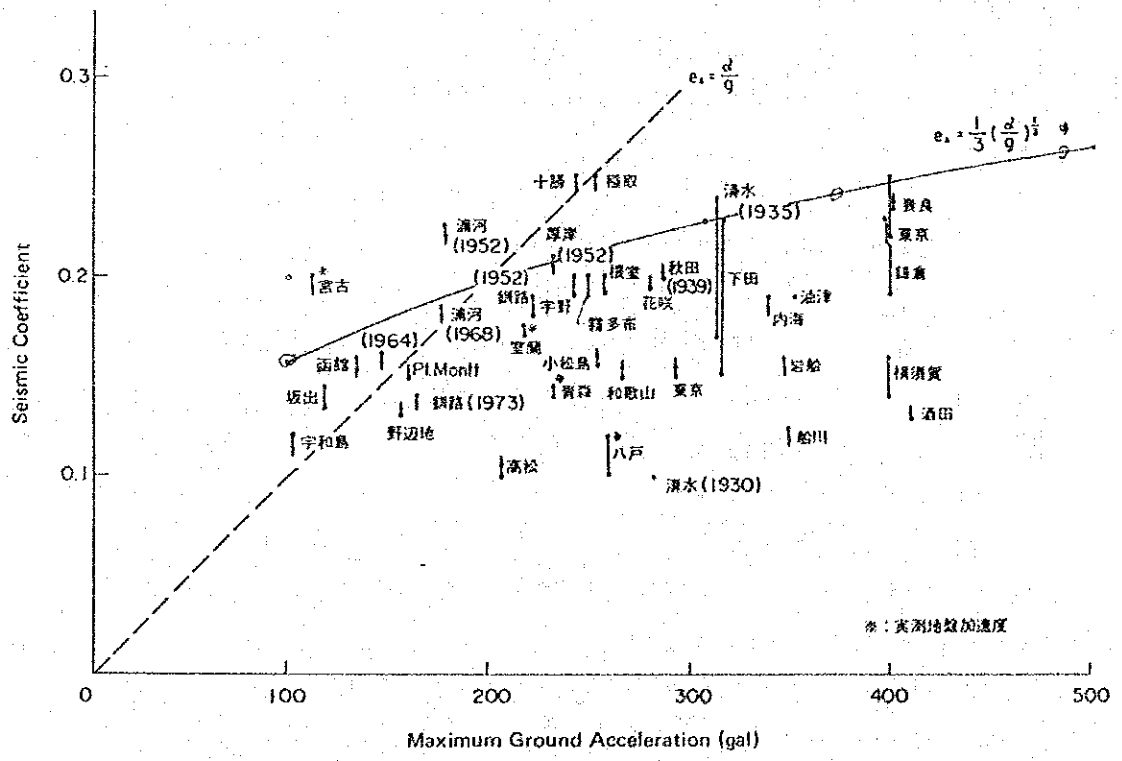
The dynamic responses of such rigid type structures as gravity quaywalls and sheet pile walls are very different from those assumed in the static analysis by the seismic coefficient method of design. Due to the effects of the dynamic components of earthquake vibrations, the static force of inertia computed by the seismic coefficient is not linearly related to the maximum acceleration of earthquake vibrations. A review on the earthquake damages to gravity quaywalls in Japan reveals the experiential relationship between the seismic coefficient and the maximum ground acceleration of earthquake vibrations as shown in Fig. III-4-3.

The seismic coefficients corresponding to the maximum ground acceleration in Fig. III-4-3 was obtained through the detailed stability investigation adopting static analysis by the seismic coefficient method for 129 gravity quaywalls in 49 ports in Japan which were damaged by 12 earthquakes. The maximum ground accelerations at the ports were estimated by the dynamic soil response analysis for earthquake vibrations based on the base rock accelerations which were determined from the strong motion accelerograms obtained by SMAC-B2 type.

Fig. III-4-3(1) shows the seismic coefficient range corresponding to the maximum ground acceleration determined through the analysis of the damaged gravity type structures. The constant ratio of the seismic coefficient to the maximum ground acceleration ranges from 0.35 to 0.85 and the average ratio thereof is given by the



(1) Range of relation between Seismic coefficient and maximum ground acceleration of damaged structures.



(2) Upper limit of damaged structures in the relation between the seismic coefficient and the maximum ground acceleration.

Fig. III-4-3 Seismic Coefficient vs. Maximum Ground Acceleration

Source: S. Noda, T. Uwabe and T. Chiba; Relation Between Seismic Coefficient and Ground Acceleration for Gravity Quaywalls, Report of the Port and Harbour Research Institute, Ministry of Transport of Japan Vol. 14, No. 4 (1975) following equation.

$$K_F = 0.6 \times \frac{\alpha}{G}$$

where K_F: seismic coefficient corresponding to the maximum ground acceleration

α: maximum ground acceleration (gal)

G: gravity acceleration = 980 gal

This indicates that gravity type quaywalls having the minimum seismic coefficient (K_F) for their stability will possibly be damaged by the corresponding maximum ground acceleration as given by the above equation.

Fig. III-4-3(2) shows the envelope curve (the upper limit) of the relation between the seismic coefficient and the maximum ground acceleration which is given by the following equation.

$$K_E = \frac{1}{3} \left(\frac{\alpha}{G}\right)^{1/3}$$

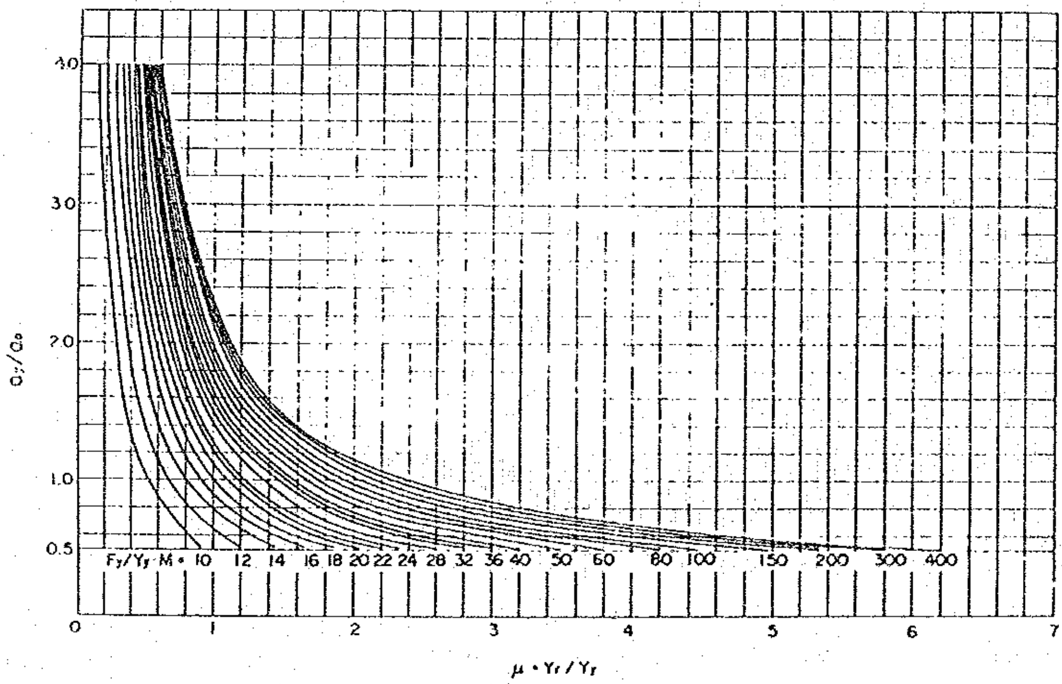
The relation indicates that the structures designed under seismic coefficients larger than those given by the above equation will decisively not be damaged from the corresponding maximum ground accelerations.

These above equations are derived from many experiences of earthquake damages to gravity type quaywalls in Japan, and are currently adopted in the assessment of the seismic stability of such rigid type port structures as gravity quaywalls, sheet pile walls and sheet pile cells. It is understood that the indirect relation between the seismic coefficient and the maximum ground acceleration may stem from the overall dynamic effects of earthquake vibrations such as frequency, amplitude, duration, velocity and the dynamic response of structures.

(ii) Open-Type Pier Structures

Open type pier structures are flexible and cannot be designed by the seismic coefficient method in view of the dynamic response characteristics. The dynamic response characteristics of vertical piled piers both in the elastic and plastic ranges have been investigated experimentally in Japan. The investigation indicates that the dynamic earthquake response of a pier structure founded on steel piles can be approximately evaluated by the adoption of the chart given in Fig. III-4-7.

The chart is obtained through the earthquake response of a pier using the one degree freedom model for three strong motion seismograms obtained by earthquakes in El Centro (1940), and in Shimizu and Kushiro in Japan (1965). Fig. III-4-4 facilitates easy evaluation of the dynamic earthquake effects on pier structures on the basis of the seismic coefficient method, and this figure is currently adopted in Japan to assess the extent of damages to pier structures by earthquake dynamic vibrations.



$a_y = F_y/W$
a_o : Seismic coefficient = α/g
F_y, Y_y : Horizontal working force and the corresponding displacement of the pier when a pile first yields
M : Static force of inertia
Y_r : Displacement of a pier corresponding to the effects of earthquake accelerations
W : Weight of the superstructure of a pier

Fig. III-4-4 Relation of a_y/a_o, $F_y/Y_y \cdot M$ and Y_r/Y_y of Open Structure

2) Causes of Damages to Berthing Structures

The intensity of earthquake vibrations varies by location depending upon the subsoil conditions. The maximum surface ground acceleration by location within the port area was estimated by our dynamic soil response analysis. The effects of the earthquake vibrations can be investigated based on the Japanese methods of evaluation for the seismic stability of existing port structures. It will be taken for granted that the seismic vibrations of the last earthquake were too severe for existing structures to maintain the structural stability if:

① Gravity Quaywalls

$K_s \min < K_F$

where Ks min: Minimum seismic coefficient at failure of structure

K_F : seismic coefficient corresponding to maximum ground acceleration (α) of the earthquake $= 0.6 \times \alpha/G$

G : gravity acceleration

② Open Pier

$\alpha > \alpha u$

where α : maximum ground acceleration of the earthquake (gal)

αu : maximum ground acceleration to cause the overall collapse of the pier

(i) The Port of Valparaiso

Enumerated below are the major categories of damages to the berthing facilities of the port observed by our visual inspection.

- Horizontal sliding or tilting movements of quaywalls partly in decimeter magnitudes.
- Settlement of berth aprons immediately behind quaywalls as well as of back-of-port yards with considerable gaps on the paved surface.
- Settlement or displacement of crane railings and railway tracks.
- Gaps or openings of decimeter scale on such quaywall elements as precast concrete blocks and coping concrete.

① Strong Motions

The maximum ground accelerations of the last earthquake were estimated to have been 238 - 334 gals by adoption of the dynamic soil response analysis. The comparison between the seismic coefficients at failure obtained by the static method of analysis and those corresponding to the maximum ground acceleration is shown in Table III-4-6.

Table III-4-6 Comparison between Seismic Coefficients for Failure and those Corresopnding to the Maximum Ground Acceleration at Valparaiso

Berth	Check El. (m)	Seismic Coefficient for failure (Ks min)		Intensity of ground motions by the earthquake 3/3/85		
		Sliding	Overturning	Location	Acceleration(α)	K_F = 0.6 x α/g
1 - 3, 5	-6.6 -11.1	0.09 0.14	0.14 0.18	Br. 2	238 gal	0.15
4	-6.6 -11.1	0.09 0.14	0.11 0.18	Br. 2	238	0.15
6, 8	-7.7 -9.1	0.12 0.17	over 0.20 over 0.20	Br. 5	313	0.19
7	-6.6 -9.1	0.15 0.18	over 0.20 over 0.20	Br. 5	313	0.19
9, 10	Sea bed	Ultimate Lateral Resistance of Pile 0.19		Br. 4	334	0.20

K_F : seismic coefficient corresponding to the maximum ground acceleration

The minimum seismic coefficients of the quaywalls of berths 1 to 8 are less for sliding failure but larger for overall overturning than those corresponding to the last earthquake's vibrations. As a result, the quaywalls slided partly but did not overturn. Table III-4-6 also indicates that the maximum ground accelerations at berths 1 to 5 are less than those at other places. This would explain why the damages to berths 1 to 3 particularly were comparatively less than those to berths 6 to 8.

The relation between the seismic coefficient and the maximum ground acceleration which can be adopted for rigid structures was also used tentatively for berths 9 and 10 (Baron pier). The pile section 4.0 m diameter would have been subjected to over-stress at or near the seabed elevation during the last earthquake.

② Long Term Water Action

Another possible cause of damages is the long-term disturbance due to water movement in front of the quaywalls. This may have resulted in a considerable loss of back-filled materials.
This may also have caused the scouring of the base mound at the toe of the quaywall structure at berth 7 (concrete caisson).
The settlement immediately behind the quaywalls of berths 1 to 3 seems to be the least owing to their location at the lee side of the breakwater, which could have minimized the loss of the back-filled soils.

③ Aging of Structures

Aging of the structural elements of the quaywalls may have caused a considerable deterioration to the original structure. This would have resulted in the loosening of the interlocking precast concrete blocks, which in addition to the water action may have intensified the loss of the backfilled materials.

④ Long Term Subsoil Settlement

Subsoil settlement on a long-term basis may have disturbed the structural elements of the quaywalls of berths 6 to 8, which are constructed on an artifically reclaimed area.

(ii) The Port of San Antonio

The probable causes of the damages to structures at San Antonio should be investigated for each individual case. In general, the severe damages at San Antonio were caused because the intensity of the earthquake vibrations at the port from the earthquake on 3/3/85 were more intense than those at the port of Valparaiso. Table III-4-7 shows the minimum seismic coefficient at failure and the seismic coefficient corresponding to the maximum ground acceleration.

Table III-4-7 Comparison between Seismic Coefficient for Failure and those Corresponding to the Maximum Ground Accelerations at San Antonio

Berth	Check El (m)	Seismic Coefficient for failure (Ks min)		Intensity of ground motions by the earthquake on 3/3/85			Remarks
		Sliding	Overturning	Location	Acceleration (α)	$K_F = 0.6 \frac{\alpha}{G}$	
1,2	-9.6	0.07	0.11	Br. 1	435 gal	0.26	
3	–	0.25		Br. 2	427	0.26	Anchor Walls
		over 0.30					Sheet Piles
4	–	0.24		Br. 2	over 427	over 0.26	Anchor Walls
		0.17 at yield					Sheet Piles
5	–	0.17	over 0.25	"	over 427	over 0.26	Retaining Walls
		0.12 for slope under the deck					
6,7	–	0.10		"	over 427	over 0.26	Seabed slope under the deck

① Berths 1 to 2

The gravity quaywalls had also been damaged by the earthquake in 1971 and suffered heavy tilting seawards. The earthquake vibrations on 3/3/85 may have resulted in complete destruction due to the inadequate seismic resistance of the damaged structure.

② Berth 3

The quaywall at berth 3 was recently constructed in 1980 - 1983, adopting steel sheet pilings anchored horizontally to the rear concrete wall by steel tie rods. Although it was originally designed to have a water depth of -10 m, the actual water depth in front of the quaywall is maintained at approximately -6.0 m at present. Due to the earthquake vibrations, the sheet pilings tilted 70 - 100 cm seaward. The stability check shows that the anchoring could have been capable of preventing the tilting of the sheet pilings towards the harbour, so possible causes of the damages will have to be carefully investigated.

Our technical study on soil liquefaction suggests a high possibility of soil liquefaction of the backfill materials behind berth 3 during the last earthquake.

The considerable tilting of the sheet pile seaward may have been caused by the liquefaction of sand deposits at or around the anchoring wall. The effects of the liquefaction may have resulted in a self-standing sheet pile wall with no horizontal restraint.

③ Berth 4

The steel sheet pile walls of berth 4 were struck by severe intensity earthquake vibrations during the last earthquake, but the damages appear minimal. Although about 15 cm horizontal displacement of the sheet pile walls is observed, it is not clear if this damage was caused by the last earthquake or by disturbance during the construction of crane rail foundations.

④ Berth 5

It appears that the inadequate stability of the L-shaped retaining wall in addition to the sea-bed slope under the deck caused the damages. The loss of the slope stability under the deck seems to have resulted in heavy settlement of the L-shaped retaining wall.

The pier deck structure suffered no damage. The chart given in Fig. III-4-4 is used to evaluate the possible horizontal displacement of the pier deck (Yr) during the last earthquake's vibrations. The result is plotted in the destruction process of the pier by the earthquake vibrations as shown in Fig. III-4-5. It seems that the last earthquake's vibrations caused a maximum horizontal deck displacement of Yr = 14 cm. The pier foundation piles would have yielded partly. But the pier did not completely collapse owing to the structural flexibility. The complete destruction of the pier would be caused by a horizontal deck displacement (Ycr) of 26 cm under more severe ground accelerations of approximately 690 gals.

⑤ Berth 6 and 7

The causes of the heavy settlement of the land side support of the deck structures of berths 6 and 7 and the tilting of the decks toward the harbour were, most likely:

- Excessive weight on the top of the rock fill embankment under the deck, and

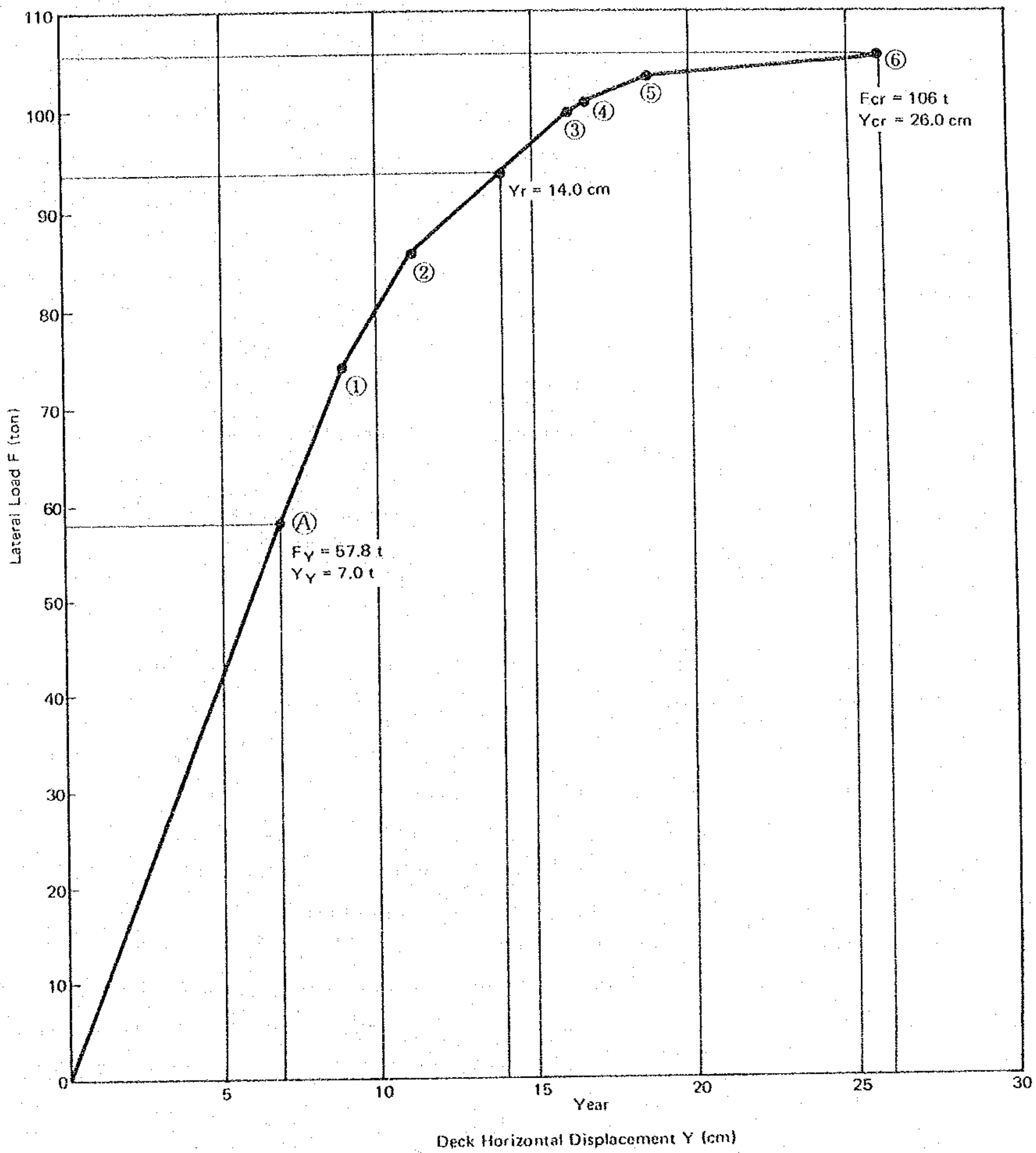
- Inadequate lateral resistance of the supporting pile foundation.

The concrete pile foundations are severely aged at the pile top and the embedment into seabed is too shallow. Moreover, the H-shaped steel piles of which welded portions are severely eroded are inadequate to withstand the vertical forces and horizontal seismic forces caused by the earthquake vibrations. The inadequacy of the slope stability under the deck could have resulted in the heavy settlement at the area behind the rock fill embankment.

3) Wharf Cranes

The existing wharf cranes are basically not designed to withstand seismic stress. However, taking the F.S.A. type crane for instance, it seems that the wharf crane is safe against a horizontal seismic coefficient of about 0.20 according to the stability calculation. It can therefore be concluded that although the cranes were not designed against earthquakes, they may be stable enough, as stress conditions in handling operations may be more severe than during earthquakes.

It can be presumed that the collapse of some of the wharf cranes was not due to the failure of the cranes themselves, but due to the deterioration or the failure of the wharf foundation.



- (A) Yielded at landside pile top
- (1) Plastic state on landside pile top
- (2) Plastic state middle pile top
- (3) Plastic state landside pile embedment
- (4) Plastic state seaside pile top
- (5) Plastic state middle pile embedment
- (6) Plastic state seaside pile embedment
- Y_r : Maximum deck displacement during earthquake vibrations
- Y_{cr}, F_{cr} : Ultimate deck displacement and the corresponding horizontal load at pier failure

Fig. III-4-5 Destruction Process of Berth No. 8 at San Antonio

III-5 Assessment of the Present Conditions of Port Structures

(1) General

The Ports of Valparaiso and San Antonio were heavily damaged by the earthquake on March, 3, 1985. Measures for restoration of the damaged facilities are urgently needed to recover the former cargo handling capacity of the ports. It is, however, deemed appropriate to propose restoration measures from a technical and economic view point as part of the overall future development of the ports.

(2) Appropriate Measures

An overall view of the damages to the port facilities gives the impression that the seismic resistance of the structures is inadequate considering the location in such an intensitive zone of earthquake activities.

However, the rehabilitation measures necessary to reinforce the seismic resistance of the damaged structures would be costly and involve a long construction period which would interfere with normal port operations. The immediate restoration plan should aim at the urgent restoration of the damaged portion of structures. The measures proposed in our immediate restoration plan, therefore, are not aimed at improving the seismic resistance of the existing structures.

It will be prudent to review such restoration measures as part of future development planning giving due consideration to the economic situation. The restoration measures are basically aimed at restoring the berths so that they can function as they did before the earthquake occured. So far as further essential rehabilitation measures are not positively taken to improve structural stability against earthquakes, utilization should be restricted as appropriate. These views lead up to believe that the immediate restoration measures as outlined below are appropriate for the urgent restoration plan.

① As the damages were relatively minor, immediate restoration works at berths 1 to 3 at Valparaiso and the open pier deck at berth 5 at San Antonio are not absolutely necessary to continue cargo handling operations as before the earthquake.

② Berthing facilities subjected to heavier damages (berths 4 to 8 at

Valparaiso and berth 3 at San Antonio) may be used for the time being if the urgent restoration measures are implemented.

③ No traffic restriction at berth 5 at San Antonio is needed except for the area behind the deck structure. However, urgent measures for restoration of the rear retaining wall must be carried out.

④ Immediate suspension of use of Baron pier (Berths 9 and 10 at the Port of Valparaiso) is mandatory because of fundamental deterioration to the superstructure caused by the severe marine environment. The usage of berths 6 and 7 at the Port of San Antonio should also be suspended, since heavy damages to the structure and deterioration of foundation piles have made these berths dangerous.

The possible utilization of these berths with appropriate rehabilitation measures may be implemented by the Chilean Government. However, this would necessitate costly investment planning within the framework of comprehensive port development.

(3) Restriction for Utilization of Berths

The immediate restoration program may necessitate various restrictions for safe cargo handling. These should be determined giving sound consideration to the engineering aspect taking into account the damaged profile of the structures. The stability check of the damaged structures is therefore considered to be the basis to determine the necessary restraints on usage within the scope of the immediate restoration plan.

Fig. III-5-1 shows the factor of safety for berthing facilities under different seismic coefficients (kh = 0.0 - 0.20) and loading conditions at the berth apron (w = 0.0 - 3.0 t/m^2). Considering the results of check calculations, the restrictions for usage of berths should be determined by the Government of Chile based on the following commentary.

① Due to insufficient structural stability, even the structures slightly damaged (berths 1 to 3 at Valparaiso, berth 4 at San Antonio) are to be carefully used to prevent over-loading due to traffic congestion at the port.

② It should be noted, however, that the earthquake resistance of berths 1 to 8 at Valparaiso and berth 4 at San Antonio are inadequate even if restrictions for berth utilization are properly set forth. So far as essential rehabilitation measures are not positively taken to improve the structural stability, utilization of these berths should preferably be more or less restricted.

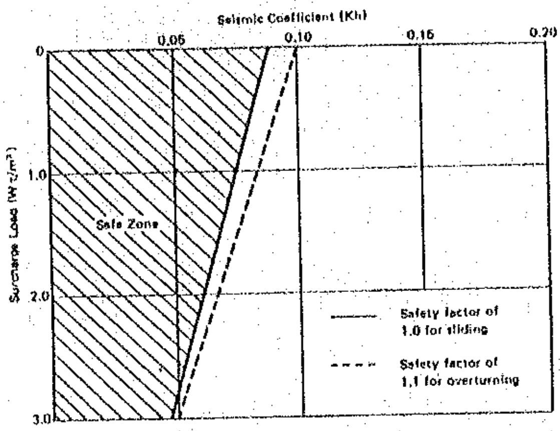
③ The lateral resistance of the concrete pile foundation at berth 4 of Valparaiso is shown in Fig. III-5-1(4) disregarding the effect of wharf crane loading. It is apparent that the lateral resistance of the piles against earthquake vibrations is insufficient although the piles will be capable of sustaining the vertical loads of wharf cranes.

④ Fig. III-5-1(7) shows the lateral resistance of the concrete pile foundations of Baron pier. As far as the normally required factor of safety for safe cargo handling operations is maintained for the possible intensity of an earthquake in the near future, the lateral resistance of the piles appears to be minimal. Moreover, our structural analysis of longitudinal beams reveals that the beams will hardly sustain the vertical loads of the superstructure because of heavy deterioration. This leads us to conclude that the berth utilization must be suspended immediately and the rehabilitation measures to Baron pier should be formulated within the framework of the future development programme of the port.

⑤ Immediate suspension of the user of berths 6 and 7 is also preferable. The deterioration and minimal seismic resistence of the foundation piles appears dangerous.

⑥ Berth 3 at San Antonio may be stable as long as the water depth in front of the berth copeline is maintained at -6.0 m. But the utilization of berth 3, or the restrictions for usage, are subject to the field investigation which is being carried out by the Government of Chile at present.

⑦ No restriction is needed at berth 5 at San Antonio after the retaining wall is properly restored based on the immediate restoration measures.



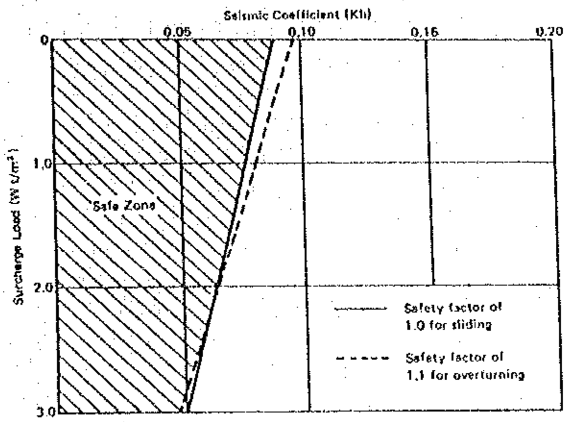
W \ Kh	0.0	0.05	0.10	0.15	0.20	Khc
0.0	1.68 2.07	1.21 1.43	0.93 1.10	0.76 0.91	0.62 0.77	0.088
1.0	1.53 1.78	1.12 1.30	0.87 1.02	0.71 0.85	0.59 0.72	0.074
2.0	1.41 1.69	1.05 1.19	0.82 0.95	0.67 0.79	0.56 0.68	0.061
3.0	1.31 1.44	0.98 1.10	0.78 0.89	0.64 0.75	0.63 0.65	0.047
Wc	t/m³ > 3.0	t/m³ 2.71	0	0	0	

Khc : Seismic coefficient at which the required factor for safety becomes minimal

Wc : Surcharge load at which the required factor for safety becomes minimal

Upper and lower figuires are the factor of safety for horizontal sliding and overturning of the quaywall, respectively.

(1) Berths No.1 and 2 of the Port of Valparaiso



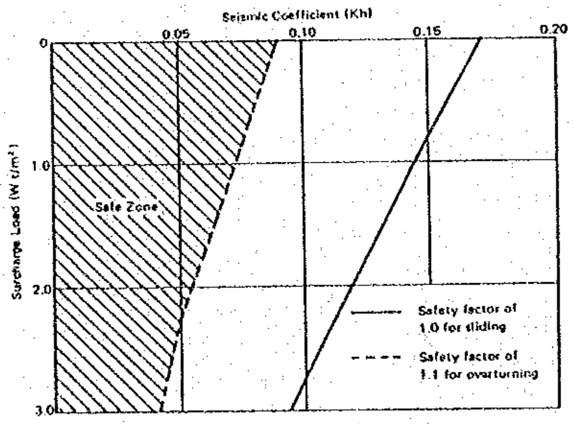
W \ Kh	0.0	0.05	0.10	0.15	0.20	Khc
0.0	1.71 1.98	1.22 1.40	0.94 1.08	0.76 0.89	0.63 0.75	0.089
1.0	1.56 1.74	1.13 1.27	0.88 1.00	0.71 0.83	0.59 0.71	0.076
2.0	1.43 1.66	1.06 1.16	0.83 0.93	0.68 0.78	0.56 0.67	0.063
3.0	1.33 1.41	1.00 1.08	0.79 0.87	0.64 0.74	0.64 0.64	0.047
Wc	t/m³ > 3.0	t/m³ 2.75	0	0	0	

Khc : Seismic coefficient at which the required factor for safety becomes minimal

Wc : Surcharge load at which the required factor for safety becomes minimal

Upper and lower figuires are the factor of safety for horizontal sliding and overturning of the quaywall, respectively.

(2) Berth No.3 at the Port of Valparaiso



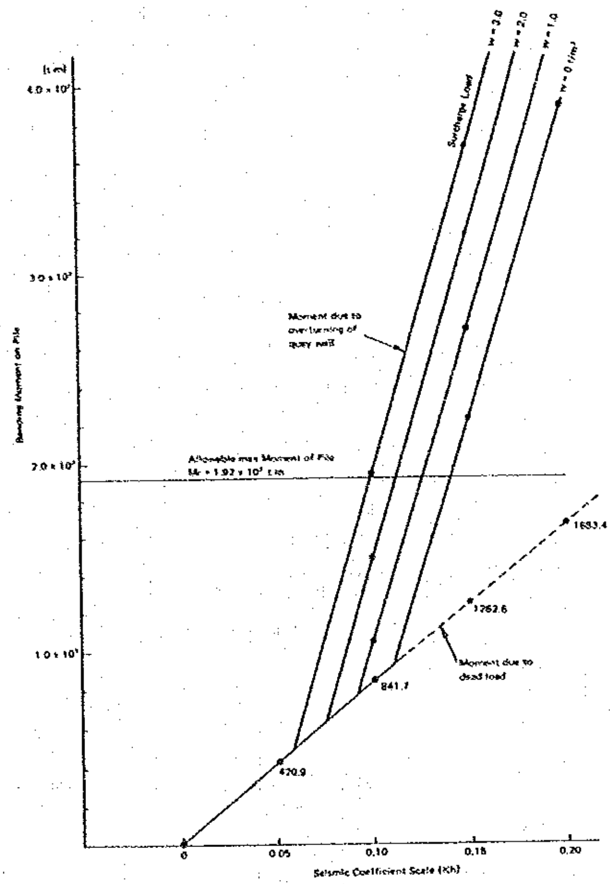
W \ Kh	0.0	0.05	0.10	0.15	0.20	Khc
0.0	1.70 1.91	1.48 1.35	1.25 1.04	1.07 0.85	0.91 0.72	0.090
1.0	1.55 1.68	1.33 1.22	1.14 0.96	0.98 0.79	0.84 0.68	0.073
2.0	1.43 1.50	1.23 1.12	1.06 0.89	0.91 0.75	0.78 0.64	0.054
3.0	1.33 1.30	1.14 1.04	0.98 0.84	0.84 0.71	0.72 0.61	0.041
Wc	t/m³ > 3.0	t/m³ 2.25	0	0	0	

Khc : Seismic coefficient at which the required factor for safety becomes minimal

Wc : Surcharge load at which the required factor for safety becomes minimal

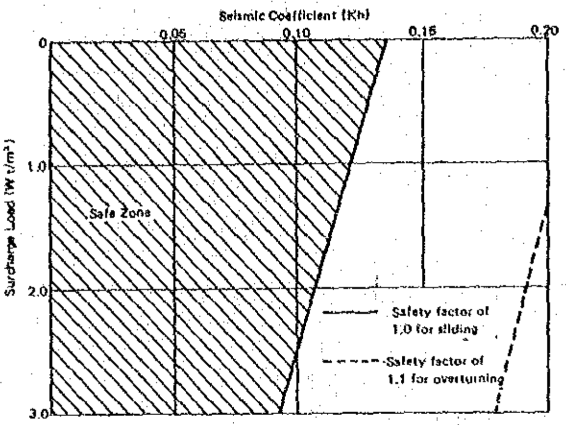
Upper and lower figuires are the factor of safety for horizontal sliding and overturning of the quaywall, respectively.

(3) Berth No.4 at the Port of Valparaiso



(4) Crane Beam Foundation Pile at Berth 4 of Valparaiso

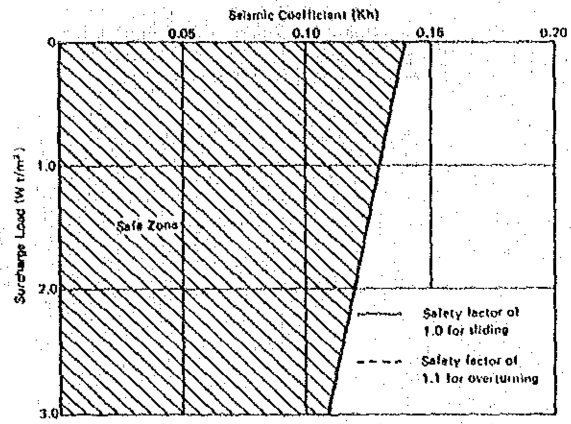
Fig. III-5-1 Stability of Existing Quaywalls



Kh / W	0.0	0.05	0.10	0.15	0.20	Khc
0.0	2.37 3.78	1.58 2.42	1.17 1.78	0.92 1.41	0.75 1.16	0.134
1.0	2.16 3.34	1.47 2.22	1.10 1.69	0.87 1.33	0.71 1.11	0.122
2.0	2.00 2.99	1.37 2.06	1.05 1.56	0.83 1.26	0.68 1.05	0.111
3.0	1.86 2.72	1.32 1.91	0.99 1.47	0.79 1.20	0.65 1.01	0.095
Wc	t/m² > 3.0	t/m² > 3.0	t/m² 2.50	0	0	

Khc : Seismic coefficient at which the required factor for safety becomes minimal
Wc : Surcharge load at which the required factor for safety becomes minimal
Upper and lower figures are the factor of safety for horizontal sliding and overturning of the quaywall, respectively.

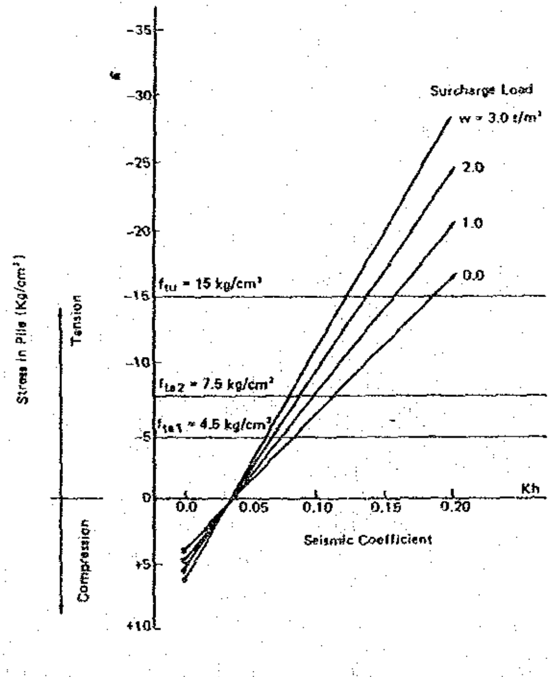
(5) Berth No.6 and 8 at the Port of Valparaiso



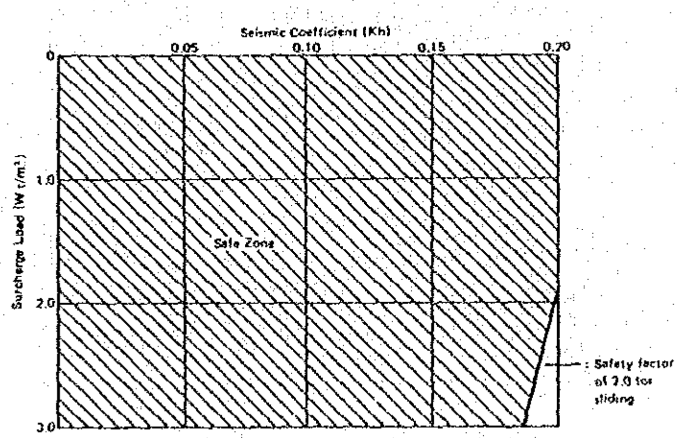
Kh / W	0.0	0.05	0.10	0.15	0.20	Khc
0.0	2.32 4.95	1.59 3.00	1.20 2.15	0.95 1.68	0.78 1.37	0.140
1.0	2.15 4.33	1.49 2.74	1.14 2.01	0.90 1.58	0.74 1.31	0.129
2.0	2.00 3.86	1.41 2.53	1.08 1.88	0.86 1.50	0.71 1.25	0.118
3.0	1.87 3.49	1.34 2.36	1.03 1.78	0.83 1.43	0.68 1.19	0.108
Wc	t/m² > 3.0	t/m² > 3.0	t/m² > 3.0	0	0	

Khc : Seismic coefficient at which the required factor for safety becomes minimal
Wc : Surcharge load at which the required factor for safety becomes minimal
Upper and lower figures are the factor of safety for horizontal sliding and overturning of the quaywall, respectively.

(6) Berth No.7 at the Port of Valparaiso



(7) Foundation Pile of Baron Pier at the Port of Valparaiso



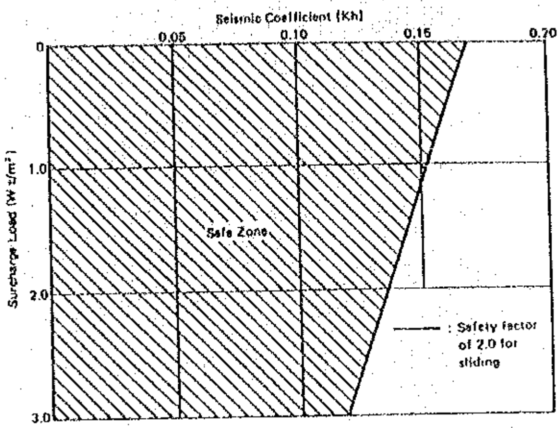
Factor of Safety for Horizontal Resistance of Anchoring in the case of -8.0 m water depth

Kh / W	0.0	0.05	0.10	0.15	0.20	Khc
0.0	6.72	5.47	4.40	3.44	2.49	0.226
1.0	5.98	4.88	3.90	3.05	2.22	0.213
2.0	5.30	4.37	3.51	2.74	1.99	0.199
3.0	4.80	3.97	3.18	2.49	1.81	0.188
Wc	t/m² > 3.0	t/m² > 3.0	t/m² > 3.0	t/m² > 3.0	t/m² 1.98	

Khc : Seismic coefficient at which the required factor for safety becomes minimal
Wc : Surcharge load at which the required factor for safety becomes minimal

(8) Berth No.3 at the Port of San Antonio

Fig. III-5-1 Stability of Existing Quaywalls



Factor of Safety for Hirizontal Resistance of Anchoring

W \ Kh	0.0	0.05	0.10	0.15	0.20	Khc
0.0	4.41	3.60	2.90	2.25	1.58	0.169
1.0	3.89	3.26	2.61	2.02	1.42	0.152
2.0	3.64	2.96	2.38	1.84	1.29	0.135
3.0	3.35	2.72	2.18	1.69	1.18	0.118
Wc	t/m² > 3.0	t/m² > 3.0	t/m² > 3.0	t/m² 1.11	0	

Khc : Seismic coefficient at which the required factor for safety becomes minimal
Wc : Surcharge load at which the required factor for safety becomes minimal

(9) Berth No.4 at the Port of San Antonio

Fig. III-5-1 Stability of Existing Quaywalls

(4) Remaining Useful Life of Existing Structures

The remaining useful life of the existing structures is closely related to the seismic risk in view of the seismic resistance of the structures. The remedial measures or repair to the damaged structures may extend the useful life of the structures, but it is difficult to evaluate the extension of the useful life in view of the aging or deterioration of the structures. As a basis of judgement, it will be appropriate to expect that the remaining useful life will be extended 5 - 10 years by the immediate restoration measures.

1) Seismic Risk

The seismic risk is detailed in section VIII of this report, and the following maximum ground acceleration expectancy (α) for the return period is used to evaluate the remaining useful life of the existing structures.

Valparaiso : $\log T_R = -2.217 + 1.605 \log \alpha$

San Antonio : $\log T_R = -2.270 + 1.715 \log \alpha$

The last earthquake was the largest since 1906, and it caused the high earthquake vibrations throughout central Chile. The maximum ground accelerations estimated by our study are 240 - 330 gals at Valparaiso and 430 - 630 gals of San Antonio on a SMAC -B2 seimograph basis.

The return period (T_R) is statistically defined as a certain magnitude of earthquake vibration which will probably recur once within a certain time span, i.e., the return period. The above seismic risk at Valparaiso and San Antonio is calculated on the basis of a indefinite time span. Considering the possible intensity of the last earthquake, it is technically considered that the maximum ground acceleration for the return period (T_R) will occur again in T_R years counted from the last earthquake in 1985.

2) Stability by the Static Method of Analysis

The stability check of the damaged structures is carried out based on the seismic coefficient method, and the minimum seismic coefficient at failure (Ks min) of the structures under a uniformly distributed load of 1.0 t/m^2 is summarized in Table III-5-1.

Table III-5-1 Min. Seismic Coefficient at Failure

Port	Berth	Seismic Coefficient at Failure		Ks min	Remarks
		Sliding	Overturning		
Valparaiso	1.2	0.075	0.10	0.075	
	3.5	0.07	0.10	0.07	
	4	0.14	0.09	0.09	
		0.17		0.17	lateral resistance of piles
	6,8	0.12	over 0.20	0.12	
	7	0.14	over 0.20	0.14	
	9,10	0.16		0.16	lateral resistance of piles
San Antonio	1,2	-		-	
	3 (-6.0m)	0.25 for anchor walls and over 0.30 for sheet piles		0.25	with corrosion protection
	4	0.24 for anchor walls and 0.17 for sheet piles		0.17	no corrosion is considered
	5	690 gals		0.12 1)	pier deck
		0.15	over 0.25		retaining walls
	6,7	Nil		Nil	lateral resistance of piles

1) equal to the seismic coefficient at which the slope under the deck fails

3) Probability of Destruction of Structures

The probability of destruction of structure is equal to the probability of the occurrence of an earthquake with an intensity sufficient to cause the destruction of the structure. The probability of the earthquake occurrence is expressed based on the random access theory as follows.

$$P(Y > y, T_D) = 1 - \{1 - P(Y > y, t = 1)\}^{T_D}$$

where $P(Y > y, T_D)$: probability of earthquake occurrence within the time span (T_D) with an intensity (Y) not less than y

$P(Y > y, t = 1)$: ditto, but within a unit time span

Because of the definition of the return period (T_R) , P (Y > y, t = 1) is equal to the reciprocal of the return period ($1/T_R$) and the above equation is modified as follows

$$P\ (Y > y,\ T_D) = 1 - \{1 - \frac{1}{T_R}\}^{T_D}$$

Fig. III-5-2 shows above probability given by the return period of the earthquake (T_R) and time span (TD).

The structure is decisively destroyed by the earthquake under the following conditions, and the probability of destruction is considered to be 1.0.

- for gravity quaywalls

  $Ks\ min < K_F$

  Ks min: minimum seismic coefficient at failure of the structure

  K_F : seismic coefficient corresponding to the maximum ground acceleration (α) of earthquake = $0.6 \times \frac{\alpha}{G}$

  G : gravity acceleration = 980 gal

- for open piers

  $\alpha > \alpha u$

where α : the maximum ground acceleration of the earthquake

αu : the ground acceleration sufficient to cause the maximum (ultimate) displacement of the pier deck (Ycu)

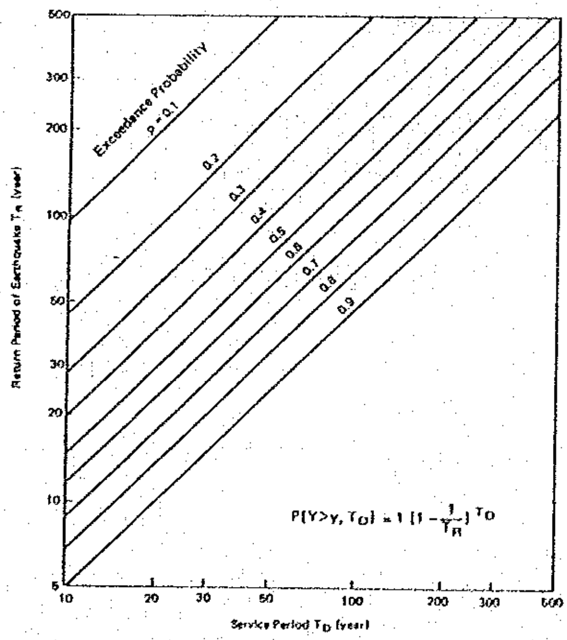


Fig. III-5-2 Exceedance Probability of Earthquake

4) Evaluation of Remaining Useful Life Expectancy

The maximum ground acceleration (α) of the earthquake which will decisively cause the destruction of the structure is converted into the return period of the earthquake (T_R). The remaining useful life expectancy (T_{D1}) can be determined for different levels of the probability of earthquake occurence P (Y > y, T_D).

The remaining useful life expectancy is evaluated as shown in Table III-5-2 for the probability P (Y > y, T_D) of 0.5, i.e., 50% probability of destruction of the structure. The useful life expectancy (T_{D2}) in view of aging or deterioration of the structure is also summarized in Table III-5-2 so that the minimum useful life expectancy (T_D min) can be determined.

The destruction risk of 0.5 is adopted herein to evaluate remaining useful life expectancy. However, the acceptable destruction risk should be determined by the Government of Chile. Moreover, the decisive factor of the remaining useful life may actually be the aging or deterioration of the structure as shown in the table. This indicates that full-scale remedial measures are needed at least once within the remaining life of the structures.

In evaluating the remaining useful life of berth no.4 at San Antonio, probable corrosion to the steel sheet piles is considered because of the enadequacy of corrosion protection. Such unknown factors as effectiveness of the sheet pile anchor to the berth no.4 at San Antonio must be clarified through comprehensive investigations such as those carried out at berth no. 3 at San Antonio by the Government.

The remaining, useful life evaluated in Table III-5-2 is based on the seismic risk expectancy of the ports. Therefore, it should be construed as a preliminary probability and only be used as a reference to help determine the need for rehabilitation measures for the berths in the framework of the future development plan of the ports.

Table III-5-2 Remaining Useful Life Expectancy

(1) The Port of Valparaiso

Berth No.		1, 2	3,5	4	6,8	7	9, 10
Ks min		0.075	0.07	0.09	0.12	0.14	0.16
α (gal)		122	114	147	196	229	261
T_R (yrs)		14	12	18	29	37	46
Useful Life	T_{D1} (yrs)	13	8	16	20	25	43
	T_{D2} (yrs)	more or less 10 - 20 yrs	5 - 10 yrs with provision of restoration measures				Nil for super-structure
	T_D min (yrs)	10	8	5-10	5-10	5-10	Nil for super-structure and 43 for piles

(2) The Port of San Antonio

Berth No.		1, 2	3 (-6.0 m)	4	5 pier	5 Retaining walls	6,7
Ks min		-	0.25	0.11	-	0.12	Nil
α (gal)		-	441 (350)	184	690	196	-
T_R (Yrs)		-	134 (124)	41	397	46	-
Useful Life	TD_1 (Yrs)	-	93 (86)	28	275	32	Nil
	T_{D2} (Yrs)	-	more or less 30 yrs with corrosion protection		commonly 30 - 50 yrs with corrosion protection		-
	T_D (min) (yrs)	-	30	28	30 - 50	30 apporx	Nil

- figures in parentheses at berth 3 are those for soil liquefaction

α : the maximum ground acceleration corresponding to Ks min = 0.6 x α/g

T_R : return period of earthquakes which cause the maximum ground acceleration (α)

T_{D1}: useful life in view of seismic resistance $P = 0.50 = 1 - (1 - \frac{1}{T_R})^{T_{D1}}$

T_{D2} : useful life in view of aging or deterioration

CHAPTER IV OVERALL CONCEPT FOR THE MASTER PLANS

IV OVERALL CONCEPT FOR THE MASTER PLANS

IV-1 General

(1) Background and Problems

1) The port of Valparaiso has a long history since a new shipping route, the Straits of Magellan, was discovered in 1520 by a Portuguese explorer, Capt. Hernando de Magallanes. Valparaiso later became the first principal port of call for vessels after passing through the straits. As the port is fortunately located near the largest city in Chile, it has continued to grow and now plays a central role in regional and national development as one of the major ports of the country. The port of Valparaiso can be classified as a typical commercial port which handles mainly general cargoes, as shown in III-2(1).

The port of San Antonio, on the other hand, was intentionally planned and constructed as a basic port for the Santiago metropolitan area. Over a period of about 70 years, the port of San Antonio has also become one of the major ports in Chile. As shown in III-2(2), the cargoes handled at the port are mostly copper and wheat, that is to say bulk cargoes, though a small volume of container cargoes is being imported.

It is important that the functions of the two ports be properly differentiated in the planning process. Otherwise, the two ports will compete with each other and scare investment funds will be wasted.

Considering that the hinterlands of the two ports are essentially the same and that the distance between the two ports is only 80 km, the *wide-range port concept* is applicable to these ports. Under this concept, the port of Valparaiso and the port of San Antonio are together to be regarded as one large port. Certainly the two ports should be considered as one unit for the planning process, and the functions of each port should be determined accordingly.

Ideally, the two ports should also be managed as one unit, perhaps named Valparaiso-San Antonio Port. However, such a management system may be impossible due to the structure of EMPORCHI. Nonetheless, this wide-range port concept is used for the planning process to prevent redundant investment.

2) The shortage of yards for cargo handling and open space for port expansion is a serious problem at both ports, though the port of San Antonio has open sand beaches to the south which seem to be caused by littoral drift.

The port of Valparaiso is limited by the national railway to the south and by roads and military facilities to the west. Moreover, the urban area of the city is rapidly approaching the waterfront because of the steep hills which surround the town. Thus, it is very difficult for EMPORCHI the port administrative body, to expand the land territory of the port from now on. The only remaining possibility for port expansion is by reclamation of sea areas, which are rather too deep for the purpose.

The port of San Antonio has, as mentioned before, some space available for future development. However, the location is not ideal for the purpose, and the soil conditions must be tested carefully from the viewpoint of aseismic design.

Fishery activities are important at San Antonio, and these will have to be considered in the planning process.

In the distant future, construction of an outside port may be necessary to accommodate increased demand.

3) Various land transportation plans are now being considered, particularly for roads which connect each port to Santiago. Needless to say, the allocation of port functions must be done taking into account the future land transportation network. Conversely, the roads should be planned in accordance with the activities of the ports.

The current road plan of the port of Valparaiso shows that two new accesses are being considered, one approaching to the east of the port and another coming around behind the hills to the west (refer to Fig. VI-2-11). The former was proposed to decrease the traffic congestion from leisure cars in summer, not for trucks travelling to and from the port.

As for the port of San Antonio, a new by-pass route is planned and the construction works have already begun on some sections. This road approaches the port from the south, where the sand beaches are located. Fig. VI-2-14 shows the approximate route of the new road.

Besides these plans, the widening of current routes to both ports by adding additional lanes or widening existing lanes is also planned.

In relation to railways, some ideas are now being considered, such as shortening the route from the port of Valparaiso to Santiago by constructing a tunnel, but these include more complex problems than roads. It can be said that the improvement of the maintenance systems is necessary to ensure regular transportation by railway.

4) Navigation control systems are important to help ships maneuver easily and safely, thus maximizing port capacity. It seems necessary to provide both ports with more aids to navigation such as light buoys for entrance channels and waiting areas, berth markings, escort boats and tugs, radars for emergency us, and so on. In response to changes in ship types and sizes, navigation control has come to play a major role at modernized ports throughout the world. Self-maneuvering of large vessels without tugs is usually strictly limited in narrow turning basins, and for carriers of dangerous cargoes, it is usually prohibited.

At the study ports, water areas for waiting, medical inspection, sheltering and turning are presently insufficient, and this is one of the main reasons why a comprehensive navigation control system is necessary.

Hence, as part of the development of the overall system, appropriate basins must be prepared as soon as possible.

5) There are some special problems at each of the ports.

At the port of Valparaiso, siltation and water pollution from sewage are beginning to occur. It is necessary to take measures to prevent these problems, taking into account the growth of the urban area in the immediate hinterland.

The Chilean Navy also affects port activities to some degree, and it may be necessary to perform studies concerning the use of port facilities from the viewpoint of port administration.

Another unique aspect of the port of Valparaiso is the question of housing. Strictly speaking, the provision of housing is not usually part of port development projects. At Valparaiso, however, it may be appropriate to construct some sort of residential units as part of the overall port development.

As the available land area for port expansion is severely limited, the port expansion may take place through reclamation of sea areas. For economic and other reasons, it would be preferable to use soil from steep land areas as landfill for the reclamation rather than to use dredged materials from deep offshore areas for this purpose.

Removing soil from the steep areas just behind the port would level out these areas which cannot be used at present, and would, effectively, create a new land area which could be used for the construction of housing.

As for the port of San Antonio, contamination of cargoes by copper powder, especially when copper mixes with wheat, has become of serious problem. Solving this problem may prove difficult because ① both copper and wheat are handled in large volumes at the port and ② since the earthquake, these cargoes are handled using some of the same facilities and equipment.

Another problem is the maneuverability of vessels in the summer season. When a ship enters the port, strong winds from the southwest, normal in that season, attack her right side, making steering extremely difficult. Generally speaking, large vessels are more affected by wind than by waves or current in bad weather conditions because their height above sea level is significant, and thus they have a relatively large surface area exposed to the wind.

(2) General Principles for the Master Plans

Considering the various factors discussed above, the general principles for formulating the master plans of the two ports are as follows.

1) The plans shall include modernization of the port facilities, operation systems and administration systems. Relevant land transportation infrastructures and the land areas adjacent to the ports shall also be developed as part of the overall development scheme.

2) The marine transportation needs of the area shall be fulfilled by the two ports, and the two ports shall not compete with each other. Rather, the facilities at the two ports shall be complementary. Overall, the two ports shall be planned as if they were one wide-range port.

3) At least one aseismic terminal shall be prepared at each of the ports.

4) The historical assets and the historical development of the ports shall

be considered in the planning process.

5) The two ports shall respond to the urban development of their respective port cities.

IV-2 Basic Concept for the Master Plans

In accordance with the analyses presented in former chapters and the general principles presented above, we can propose the basic concepts for each of the master plans more concretely as follows.

(1) The Port of Valparaiso

1) Establishment of the Base Port

(i) The Base Port for Container Cargo

General cargoes are imported and exported through the port, and more facilities for handling containers shall be provided in response to increase containerization throughout the world. The container terminal must provide a level of service equivalent to that provided at mojor container ports in other countries, and for the purpose, the berth length and depth, the area of handling yards and freight stations, the handling system and the capacity of container cranes shall all meet international standards.

(ii) The Base Port for Foreign General Cargo

The length and depth of the berths for oceangoing vessels have to be improved in response to the increase in the average size of such vessels, and the aprons of these berths must also be improved as much as possible. Furthermore, the sheds located just behind these berths must be relocated and reconstructed in order to mechanize the cargo handling system.

(iii) The Base Port for Domestic General Cargo

The berths for coastal ships must be developed to match changes in the size and types of such vessels. This port should be designed to provide inhabitants of remote regions with a level of service equivalent to that available in the metropolitan region.

(iv) Aseismic Terminal

Aseismic facilities which are designed to withstand earthquakes with a magnitude of up to 8 shall be prepared to serve as a lifeline for the community in case of earthquake. These facilities will also be used to support the essential economic activities in the hinterland following a major earthquake. In ordinary times, these berths shall be used for general purposes.

2) Separation of Functions

The container terminal shall be located separate from the other terminals to ensure sufficient space for cargo handling and future expansion taking into consideration natural and transportation conditions. Moreover, the foreign and domestic terminals shall also be separated.

3) Expansion by Reclamation

The requisite land area for port expansion shall be obtained through reclamation of sea areas. This work should be acceptable to the local government as it will promote urban renewal.

4) Realization of a Safe Port

Concerning navigation, the port has to be improved and proper facilities and systems have to be developed for vessels to enter, wait, berth, and go out safely even in bad weather, strong winds and high waves. For this purpose, breakwaters shall be considered as the one of the possible measures in so far as they are technically and financially feasible.

5) Preparation of Recreation Areas

In addition to preventing water polution, attractive recreational zones, such as marinas and parks, should be provided for the regional inhabitants.

(2) The Port of San Antonio

1) Establishment of the Base Port

(i) The Base Port for Bulky Cargo

Bulk cargoes are imported and exported through the port, and efficient facilities for handling such cargoes shall be provided in response to the changes in the types and sizes of bulk carriers. Warehouses and tanks as well as yards for stocking bulk cargoes shall also be prepared to improve efficiency and ensure national economic security.

(ii) The Terminal for Multi-Purpose Use

One berth is required to handle containers, heavy cargoes and bulk cargoes.
This multi-purpose terminal will be used for various purposes as needed. The berth is very important because it will also function as a supplementary container berth for the port of Valparaiso.

(iii) Aseismic Terminal

At San Antonio, aseismic facilities which are designed to withstand earthquakes with a magnitude of up to 8 shall also be prepared to serve as a lifeline in case of emergency and support the essential economic activities of the hinterland thereafter. This is a dual backup system with the aseismic facilities at the port of Valparaiso. In case of a severe earthquake, even if one of these aseismic terminals were destroyed, there is a reasonable likelihood that the other one could still be used.
The aseismic facilities at San Antonio will also be used for general purposes in ordinary times.

2) Separation of Functions

The berths for fishery activities and those for commercial functions must be located as far from each other as possible, taking into consideration the location of the fish factory. Moreover, among the commercial facilities, the facilities for handling dirty cargoes should be separated from those for clean cargoes to prevent contamination.

3) Port Expansion

As the sea areas of the port are strictly limited, any excpansion of the port shall take place on existing land areas. The inside waters of the port should be protected from high waves, and sufficient space should be secured for the maneuvering of turning vessels.

4) Realization of a Safe Port

The port has to be improved and proper facilities and systems have to be developed for vessels to enter, wait, berth and go out safely even in bad weather, strong winds and high waves. For this purpose, the seashore inside the port shall be used to break waves as one of the solutions of this problem.