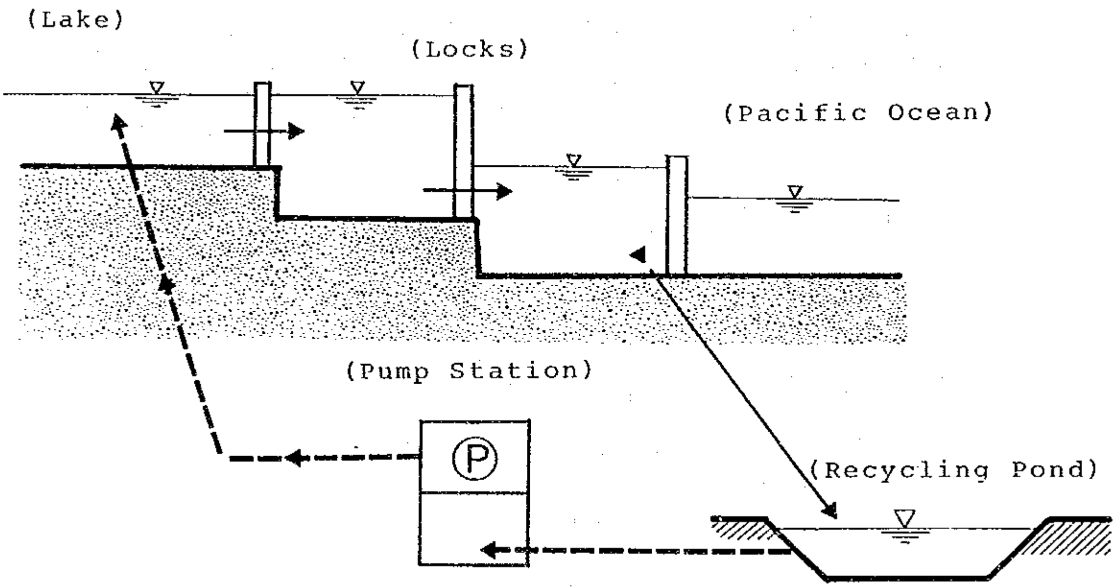
The pond has approximately 1.5 km2 in area for a set of pump station. The effective water level range would be between -2.3 ~ -3.4m at The Pacific Side and -0.1 ~ -1.2m at The Atlantic Side respectively. A discharge channel to the surge basin extends about 800 meters (ref. Fig. 4.1.4). The width and depth of the channel is chosen according to the required number of pumping stations.

The following schematic drawing shows how the recycling pond is used.



(4) Pump Stations

A Pump station which has a capacity of 60 m3/sec. is provided between the recycling pond and the surge basin and the approximate location of the pump station has been proposed in Fig. 4.1.3 and Fig. 4.1.4.

The number of pump stations would be decided according to the transit capacity of the canal and whether new storage dams are provided or not. In the Summation Tables the number of pump stations (not the number of pumps) is shown.

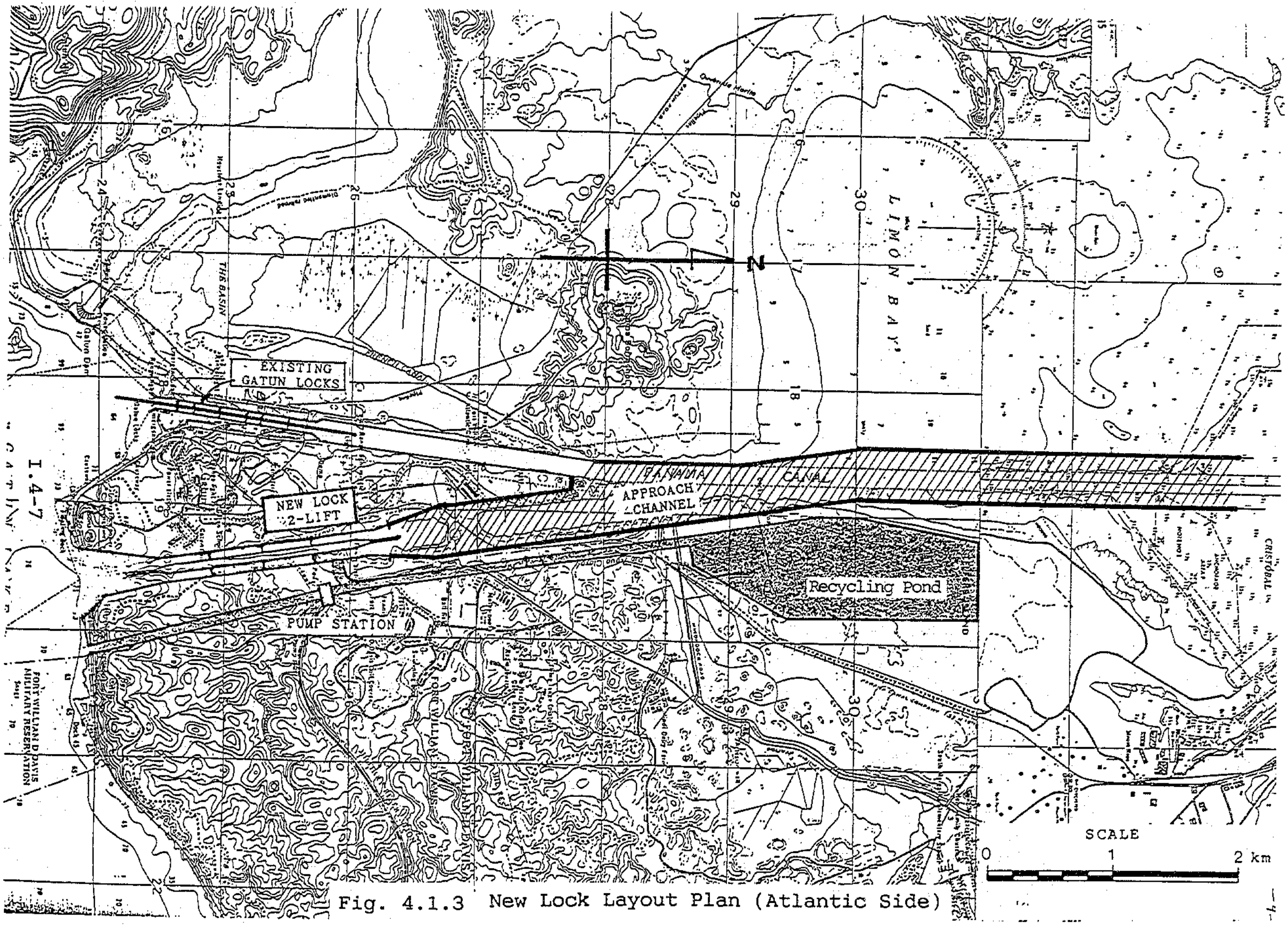


Fig. 4.1.3 New Lock Layout Plan (Atlantic Side)

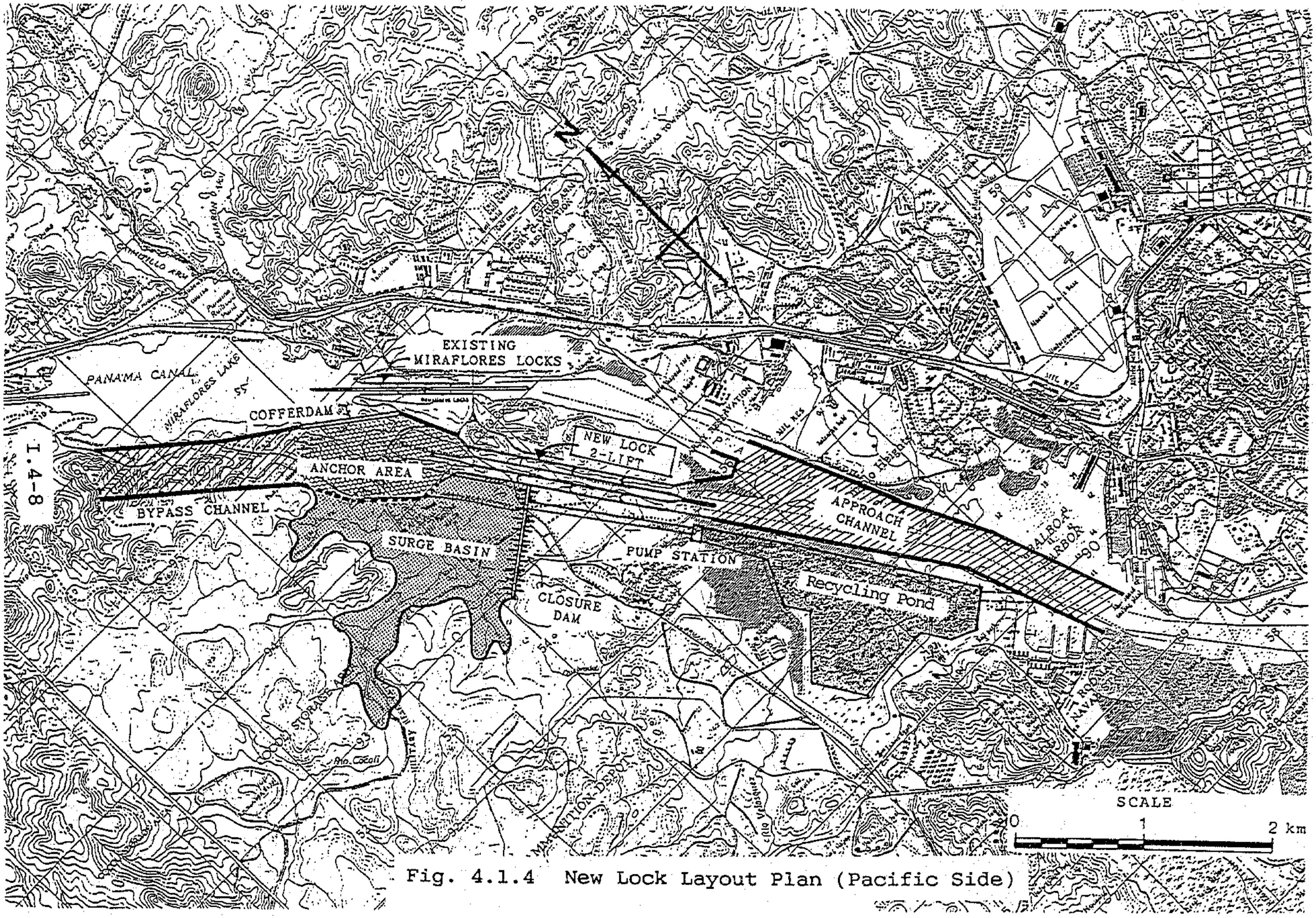
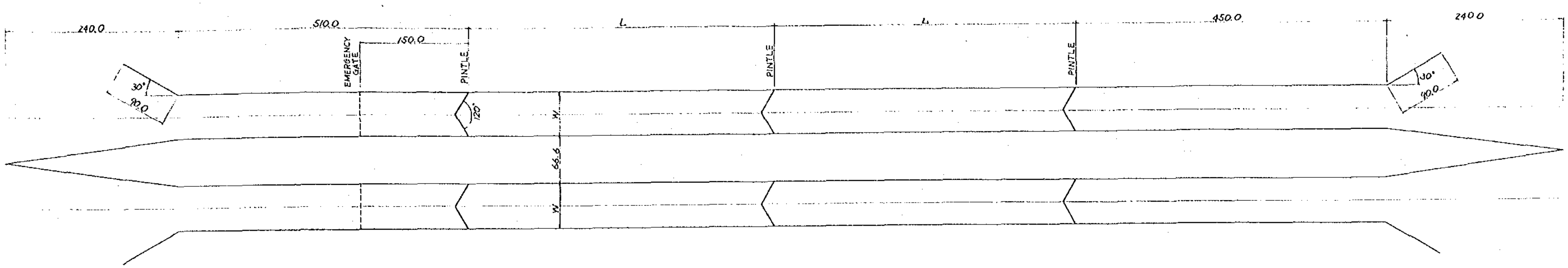


Fig. 4.1.4 New Lock Layout Plan (Pacific Side)



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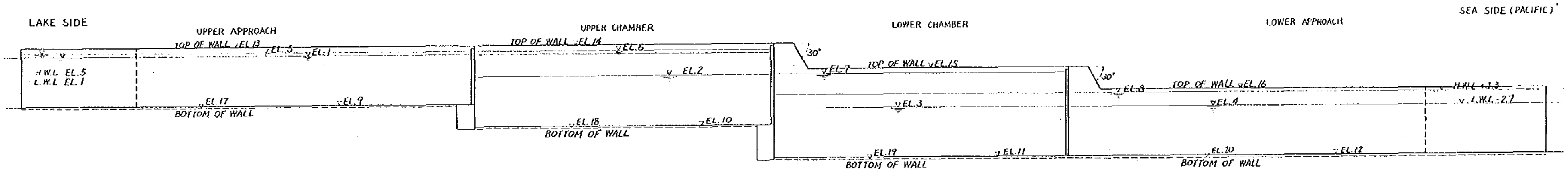


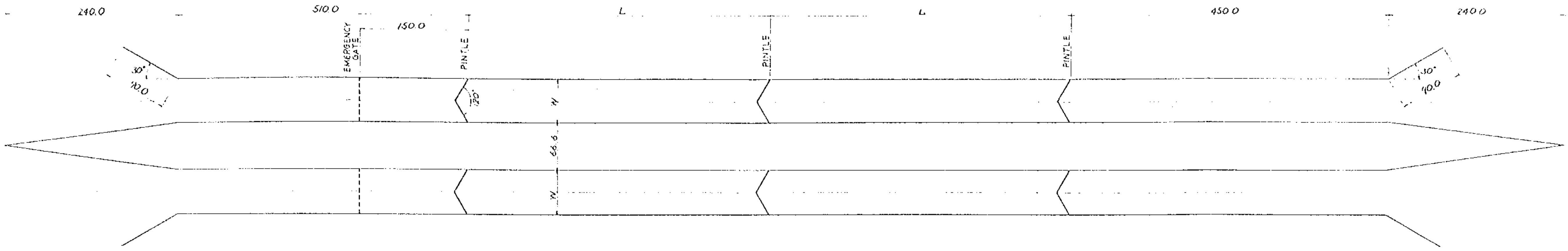
PROFILE

250,000 DWT VESSEL LOCK

STUDY CASE	LOCK SIZE				dSE (ft)	LOWEST WATER SURFACE ELEVATION				HIGHEST WATER SURFACE ELEVATION				BOTTOM ELEVATION				TOP OF WALL				BOTTOM OF WALL			
	DWT	L	W	D		GATUN EL.1	UPP LOCK EL.2	LOW LOCK EL.3	PACIFIC EL.4	GATUN EL.5	UPP LOCK EL.6	LOW LOCK EL.7	PACIFIC EL.8	GATUN EL.9	UPP LOCK EL.10	LOW LOCK EL.11	PACIFIC EL.12	GATUN EL.13	UPP LOCK EL.14	LOW LOCK EL.15	PACIFIC EL.16	GATUN EL.17	UPP LOCK EL.18	LOW LOCK EL.19	PACIFIC EL.20
L-1	100,000	319	47	19	90	+26.1	+13.7	-2.7	-2.7	+27.6	+27.6	+13.7	+3.3	+7.1	-5.3	-21.7	-21.7	+30.3	+30.3	+16.4	+6.0	+2.0	-11.3	-27.7	-27.7
L-2	100,000	319	47	19	85	+24.6	+12.9	-2.7	-2.7	+26.1	+26.1	+12.9	+3.3	+5.6	-6.1	-21.7	-21.7	+28.8	+28.8	+15.6	+6.0	+0.5	-12.1	-27.7	-27.7
L-4	150,000	363	54	21	90	+26.1	+13.7	-2.7	-2.7	+27.6	+27.6	+13.7	+3.3	+5.1	-7.3	-23.7	-23.7	+30.3	+30.3	+16.4	+6.0	0.0	-13.3	-29.7	-29.7
L-5	150,000	363	54	21	85	+24.6	+12.9	-2.7	-2.7	+26.1	+26.1	+12.9	+3.3	+3.6	-8.1	-23.7	-23.7	+28.8	+28.8	+15.6	+6.0	-1.5	-14.1	-29.7	-29.7
L-7	250,000	428	63	24	90	+26.1	+13.7	-2.7	-2.7	+27.6	+27.6	+13.7	+3.3	+2.1	-10.3	-26.7	-26.7	+30.3	+30.3	+16.4	+6.0	-3.0	-16.3	-32.7	-32.7
L-8	250,000	428	63	24	85	+24.6	+12.9	-2.7	-2.7	+26.1	+26.1	+12.9	+3.3	+0.6	-11.1	-26.7	-26.7	+28.8	+28.8	+15.6	+6.0	-4.5	-17.1	-32.7	-32.7
L-10	100,000	319	47	19	85	+24.6	+12.9	-2.7	-2.7	+26.1	+26.1	+12.9	+3.3	+5.6	-6.1	-21.7	-21.7	+28.8	+28.8	+15.6	+6.0	+0.5	-12.1	-27.7	-27.7
L-13	150,000	363	54	21	85	+24.6	+12.9	-2.7	-2.7	+26.1	+26.1	+12.9	+3.3	+3.6	-8.1	-23.7	-23.7	+28.8	+28.8	+15.6	+6.0	-1.5	-14.1	-29.7	-29.7
L-16	250,000	428	63	24	85	+24.6	+12.9	-2.7	-2.7	+26.1	+26.1	+12.9	+3.3	+0.6	-11.1	-26.7	-26.7	+28.8	+28.8	+15.6	+6.0	-4.5	-17.1	-32.7	-32.7

Note: Hatched mark is iullustlated Fig. 4.1.6 and Fig. 4.1.7

Fig. 4.1.5 High Rise Lock : General Dimensions



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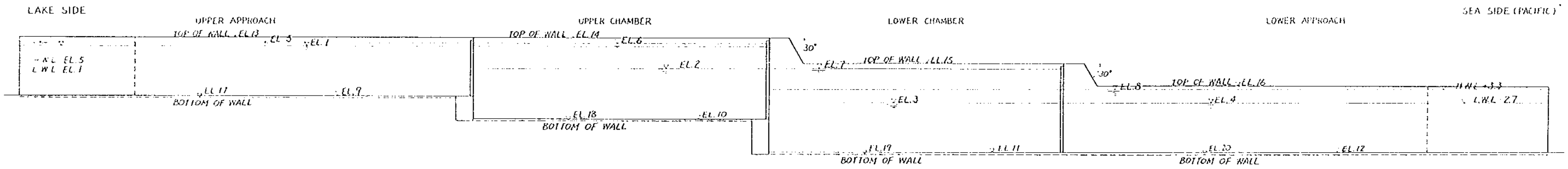


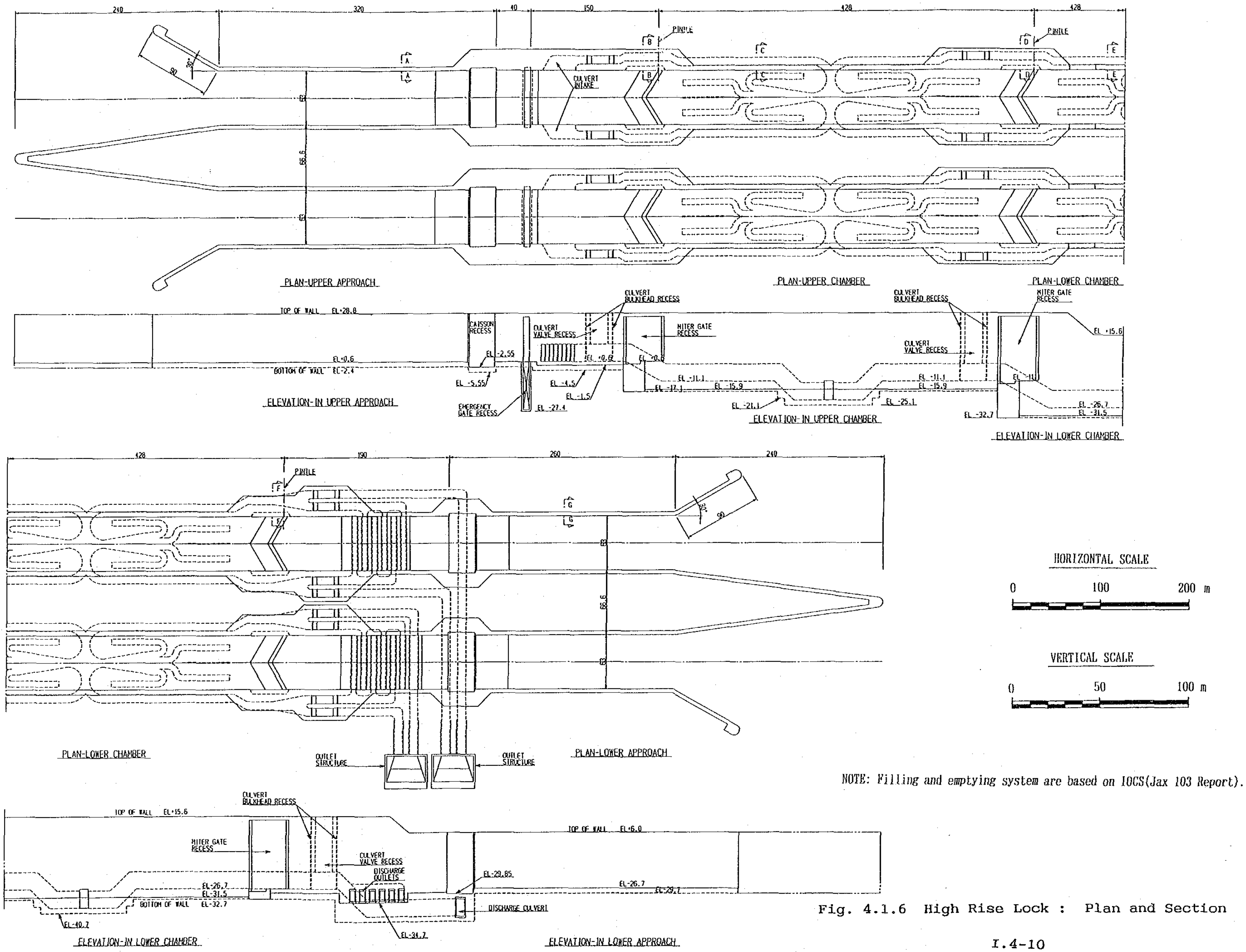
PROFILE

250,000 DWT VESSEL LOCK

STUDY CASE	LOCK SIZE				RISE (FT)	LOWEST WATER SURFACE ELEVATION				HIGHEST WATER SURFACE ELEVATION				BOTTOM ELEVATION				TOP OF WALL				BOTTOM OF WALL			
	DWT	L	W	D		GATUN EL.1	UPP LOCK EL.2	LOW LOCK EL.3	PACIFIC EL.4	GATUN EL.5	UPP LOCK EL.6	LOW LOCK EL.7	PACIFIC EL.8	GATUN EL.9	UPP LOCK EL.10	LOW LOCK EL.11	PACIFIC EL.12	GATUN EL.13	UPP LOCK EL.14	LOW LOCK EL.15	PACIFIC EL.16	GATUN EL.17	UPP LOCK EL.18	LOW LOCK EL.19	PACIFIC EL.20
L-1	100,000	319	47	19	90	+26.1	+13.7	-2.7	-2.7	+27.6	+27.6	+13.7	+3.3	+7.1	-5.3	-21.7	-21.7	+30.3	+30.3	+16.4	+6.0	+2.0	-11.3	-27.7	-27.7
L-2	100,000	319	47	19	85	+24.6	+12.9	-2.7	-2.7	+26.1	+26.1	+12.9	+3.3	+5.6	-6.1	-21.7	-21.7	+28.8	+28.8	+15.6	+6.0	+0.5	-12.1	-27.7	-27.7
L-4	150,000	363	54	21	90	+26.1	+13.7	-2.7	-2.7	+27.6	+27.6	+13.7	+3.3	+5.1	-7.3	-23.7	-23.7	+30.3	+30.3	+16.4	+6.0	0.0	-13.3	-29.7	-29.7
L-5	150,000	363	54	21	85	+24.6	+12.9	-2.7	-2.7	+26.1	+26.1	+12.9	+3.3	+3.6	-8.1	-23.7	-23.7	+28.8	+28.8	+15.6	+6.0	-1.5	-14.1	-29.7	-29.7
L-7	250,000	428	63	24	90	+26.1	+13.7	-2.7	-2.7	+27.6	+27.6	+13.7	+3.3	+2.1	-10.3	-26.7	-26.7	+30.3	+30.3	+16.4	+6.0	-3.0	-16.3	-32.7	-32.7
L-8	250,000	428	63	24	85	+24.6	+12.9	-2.7	-2.7	+26.1	+26.1	+12.9	+3.3	+0.6	-11.1	-26.7	-26.7	+28.8	+28.8	+15.6	+6.0	-4.5	-17.1	-32.7	-32.7
L-10	100,000	319	47	19	85	+24.6	+12.9	-2.7	-2.7	+26.1	+26.1	+12.9	+3.3	+5.6	-6.1	-21.7	-21.7	+28.8	+28.8	+15.6	+6.0	+0.5	-12.1	-27.7	-27.7
L-13	150,000	363	54	21	85	+24.6	+12.9	-2.7	-2.7	+26.1	+26.1	+12.9	+3.3	+3.6	-8.1	-23.7	-23.7	+28.8	+28.8	+15.6	+6.0	-1.5	-14.1	-29.7	-29.7
L-16	250,000	428	63	24	85	+24.6	+12.9	-2.7	-2.7	+26.1	+26.1	+12.9	+3.3	+0.6	-11.1	-26.7	-26.7	+28.8	+28.8	+15.6	+6.0	-4.5	-17.1	-32.7	-32.7

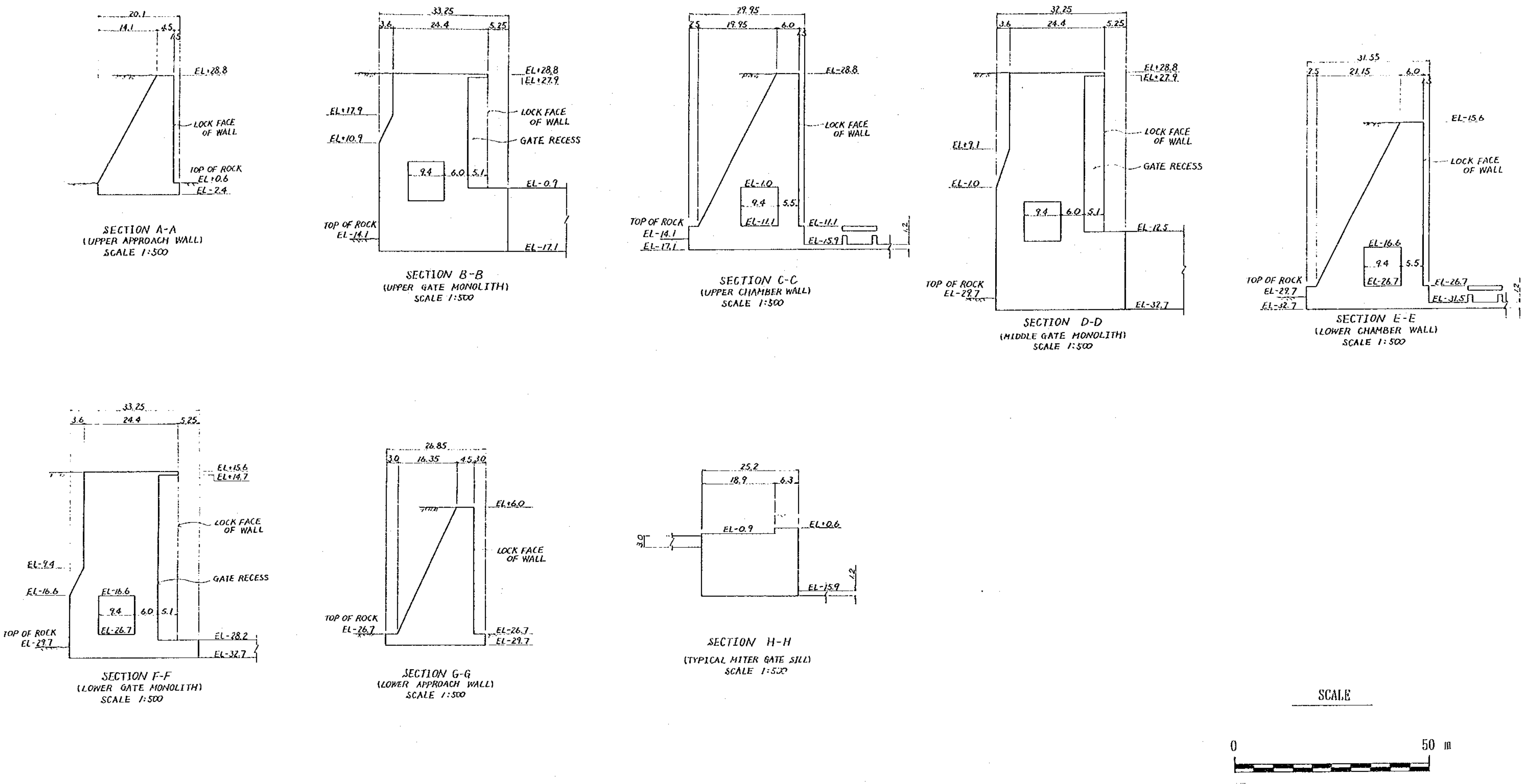
Note: Hatched mark is iullustlated Fig. 4.1.6 and Fig. 4.1.7

Fig. 4.1.5 High Rise Lock : General Dimensions



NOTE: Filling and emptying system are based on IOCS(Jax 103 Report).

Fig. 4.1.6 High Rise Lock : Plan and Section



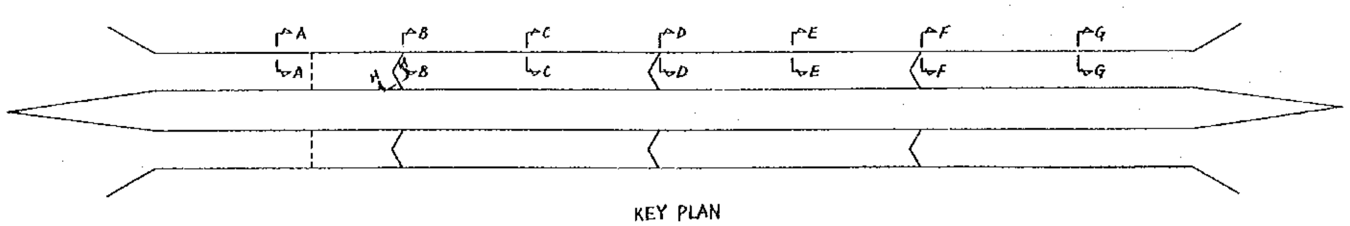
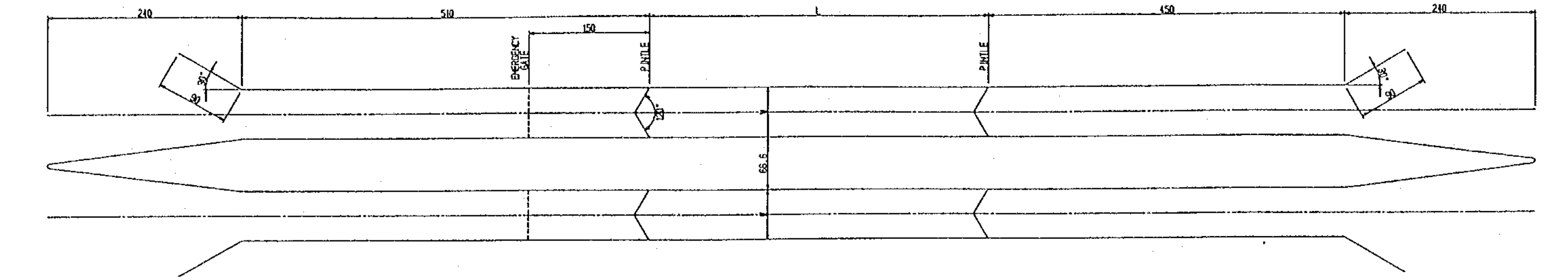


Fig. 4.1.7 High Rise Lock : Cross Section



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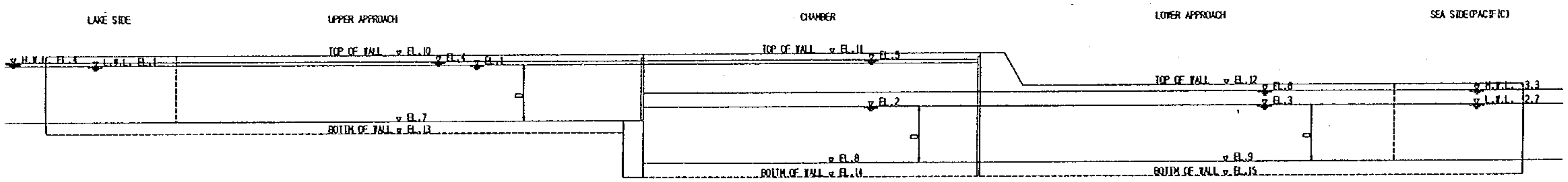
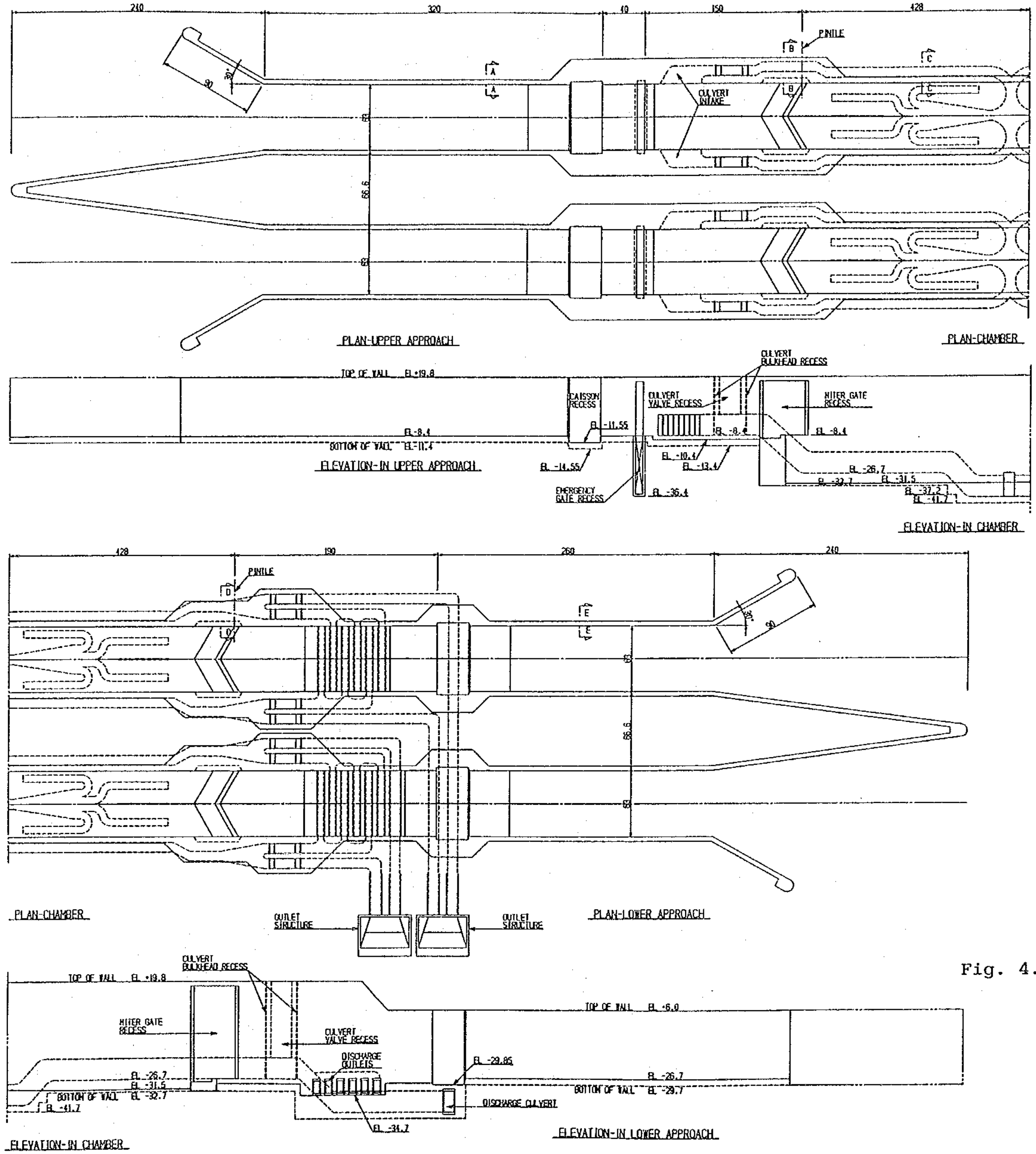


PROFILE

250,000 DWT VESSEL LOCK

STUDY CASE	LOCK SIZE				RISE (ft)	LOWEST WATER SURFACE ELEVATION			HIGHEST WATER SURFACE ELEVATION			BOTTOM ELEVATION			TOP OF WALL			BOTTOM OF WALL		
	DWT	L	W	D		GATUN EL.1	LOCK EL.2	PACIFIC EL.3	GATUN EL.4	LOCK EL.5	PACIFIC EL.6	GATUN EL.7	LOCK EL.8	PACIFIC EL.9	GATUN EL.10	LOCK EL.11	PACIFIC EL.12	GATUN EL.13	LOCK EL.14	PACIFIC EL.15
L-3	100,000	319	47	19	55	+15.6	-2.7	-2.7	+17.1	+17.1	+3.3	-3.4	-21.7	-21.7	+19.8	+19.8	+6.0	-8.5	-27.7	-27.7
L-6	150,000	363	54	21	55	+15.6	-2.7	-2.7	+17.1	+17.1	+3.3	-5.4	-23.7	-23.7	+19.8	+19.8	+6.0	-10.5	-29.7	-29.7
L-9	250,000	428	63	24	55	+15.6	-2.7	-2.7	+17.1	+17.1	+3.3	-8.4	-26.7	-26.7	+19.8	+19.8	+6.0	-13.5	-32.7	-32.7
L-11	100,000	319	47	19	55	+15.6	-2.7	-2.7	+17.1	+17.1	+3.3	-3.4	-21.7	-21.7	+19.8	+19.8	+6.0	-8.5	-27.7	-27.7
L-12	100,000	319	47	19	30	+8.1	-2.7	-2.7	+9.6	+9.6	+3.3	-10.9	-21.7	-21.7	+12.3	+12.3	+6.0	-16.0	-27.7	-27.7
L-14	150,000	363	54	21	55	+15.6	-2.7	-2.7	+17.1	+17.1	+3.3	-5.4	-23.7	-23.7	+19.8	+19.8	+6.0	-10.5	-29.7	-29.7
L-15	150,000	363	54	21	30	+8.1	-2.7	-2.7	+9.6	+8.6	+3.3	-12.9	-23.7	-23.7	+12.3	+12.3	+6.0	-18.0	-29.7	-29.7
L-17	250,000	428	63	24	55	+15.6	-2.7	-2.7	+17.1	+17.1	+3.3	-8.4	-26.7	-26.7	+19.8	+19.8	+6.0	-13.5	-32.7	-32.7
L-18	250,000	428	63	24	30	+8.1	-2.7	-2.7	+9.6	+9.6	+3.3	-15.9	-26.7	-26.7	+12.3	+12.3	+6.0	-21.0	-32.7	-32.7

Fig. 4.1.8 Low Rise Lock : General Dimensions



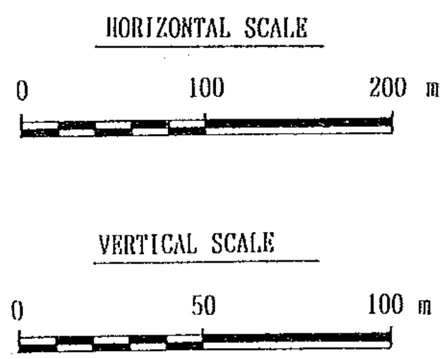


Fig. 4.1.9 Low Rise Lock : Plan and Section

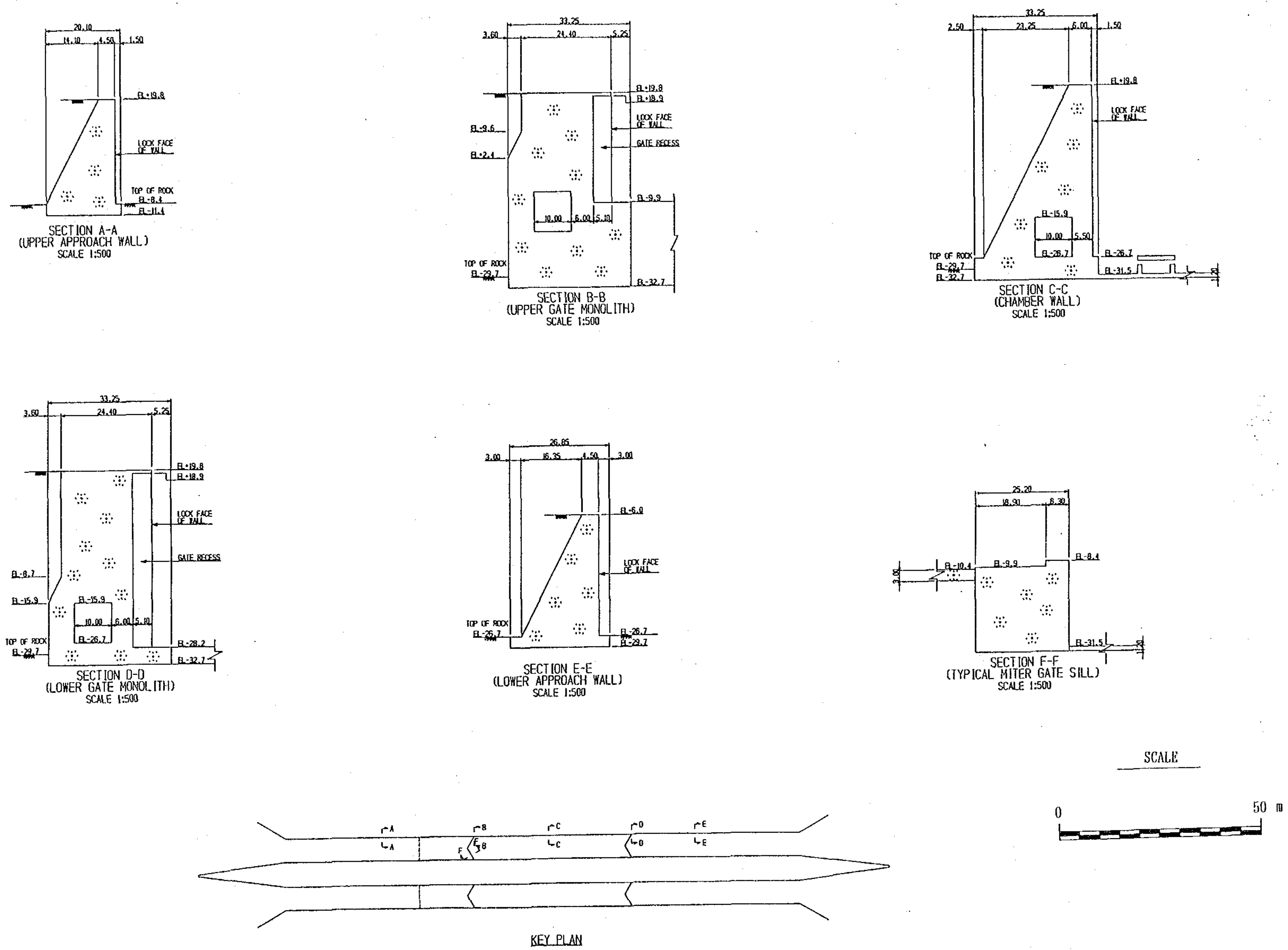


Fig. 4.1.10 Low Rise Lock : Cross Section

4.2 Gate Leaves

4.2.1 General Information

(1) General Introduction

This section intends to give general technical information which are common to all kinds of gates to be utilized in lock type canal, and are fundamental conditions, philosophy and important procedures of their conceptual designs the results of which are going to be shown in the next section.

The kind of gates to be studied includes Lock Gate, Culvert Gate, Emergency Gate and Maintenance Gate. Lock Gate plays a major role in canal lock functions and opens or closes the lock entrances according to ship transits. Culvert Gate also plays another major role. It opens or closes culvert channels in the lock walls and controls water flow in the culvert channel running into or out of lock chambers and, eventually, lifts ships in the chamber up or down according to directions of ship transits. Emergency Gate will swiftly close the lock in case of emergency such as fractures or collapses of Lock Gates due to ship collisions and prevent the areas surrounding the lock from fatal disasters or keep intensity of damages due to the accidents as low as possible. Maintenance Gate is used to close the extreme ends of the lock whenever it becomes necessary for maintenance works in the lock chamber at dry condition.

<u>Comparison of Lock Gates for locks in the world</u>

Locks for ships in the world can be divided into two groups, an entrance lock for docks and a navigation lock for canals. Table 4.2.1 shows the entrance locks in United Kingdom and India. The example of India was shown together with UK examples because its engineering was made by a British consultant firm. This table also shows separately the entrance locks in the continent. These two cases apparently shows good correlations between the lock widths and the gate types but, at the same time, there seems to be a slight difference in their histories. There was not remarkable information of the entrance locks in any other part of the world, though the time tightness did not allow to pay the similar attention to the Southern Hemi-sphere. Table 4.2.2 shows the navigation locks all together. Only typical cases have been selected for the table from each waterway. The St Lawrence seaway and the Panama canal are remarkable among them for the reason because they can accommodate bigger ships with deeper draft. St Lawrence much prevails Panama as long as a lift per a chamber is concerned. Notwithstanding the smaller water depths in other cases, many high lift locks are seen not only in the America continent but also in Europe too.

Table 4.2.3 was converted from Table 4.2.2 to find out any correlations between the principal technical data and gate types. A rule of the conversion was just simplification. Only extreme one case was chosen from each waterway and the names of gate type on the Table 4.2.2 were replaced by gate movement when the gate opened. The cases enclosed by the stressed lines on Table 4.3.3 are all with a high lift compared with their water depths. This relation easily leads us to correlate them with a gate type; i.e. a combination of drop type and rise type as seen on the enclosed area. There are also several exceptions both in and out of the enclosed area. Exceptional selections for hydraulic steel structures are not unusual and possible reasons with which each exceptional selections might be justified could be listed up for all these cases.

Table 4.2.1 Records of Lock Gates

ENTRANCE LOCK IN UK AND INDIA

COUNTRY	NAME OF LOCK OR DOCK	LOCK IN M		HEIGHT IN M		LIFT IN M	GATE TYPE	REMARK
		LENGTH	WIDTH	GATE	WATER			
UK	CHICHESTER HARBOUR	32	7.6		5.6		SECTOR	
UK	SHADWELL LOCK	107	18.3		8.5		MITER	
UK	BARRY DOCK (S.WALES)	197	19.8		14.8		MITER	
UK	GREENLAND	168	24.4		9.8		MITER	
UK	GALLION LOWER	168	24.4		10.5		MITER	
UK	SWANSEA DOCK	265	27.4		12.2		MITER	
UK	KING GEORGE	244	30.5		11.6		MITER	
UK	NEWPORT DOCK	305	30.5		16.8		MITER	WATER DEPTH IN DOCK
UK	GRANGEMOUTH DOCK	237	30.5		11.6		MITER	
UK	LEITH HARBOUR	259	33.5	14.2			SLIDE	
UK	PORT OF LIVERPOOL	251	39.6	17.1			SLIDE	
INDIA	HALDIA DOCK	380	40.0		13.7		SLIDE	WATER DEPTH IN DOCK
UK	WEST DOCK OF BRISTOL	366	42.7		17.1		SLIDE	NEEDS CONFIRMATION

ENTRANCE LOCK IN THE CONTINENT

COUNTRY	NAME OF LOCK OR DOCK	LOCK IN M		HEIGHT IN M		LIFT IN M	GATE TYPE	REMARK
		LENGTH	WIDTH	GATE	WATER			
FRANCE	DUQUESNE DOCK,DIEPPE		15.0		12.0		SECTOR	
GERMANY	HOLTENAU	125	25.0		10.1		MITER	
GERMANY	BRUNSBUTTEL	125	25.0		10.2		MITER	
FRANCE	THE PORT OF LE HAVRE	290	25.0		15.3		SLIDE	PLANNED IDEA
FRANCE	THE PORT OF LE HAVRE	300	42.0		20.3		SLIDE	PLANNED IDEA
GERMANY	HOLTENAU	310	45.0		13.8		SLIDE	
GERMANY	BRUNSBUTTEL	310	45.0		13.8		SLIDE	
BELGIUM	ANTWERP BAUDIN LOCK	360	45.0		14.3		SLIDE	
HOLLAND	IJMNIDEN	400	50.0				SLIDE	
BELGIUM	ANTWERP ZANTFLIET	500	57.0	22.9	21.0		SLIDE	
FRANCE	THE PORT OF LE HAVRE	360	60.0		21.3		SLIDE	PLANNED IDEA
BELGIUM	ANTWERP BERENDRECHT	500	68.0	22.6	21.0		SLIDE	

Table 4.2.2 Records of Lock Gates

NAVIGATION LOCK

COUNTRY	NAME OF LOCK	NAME OF RIVER / CANAL	LOCK IN M		WATER	LIFT		UPPER LOCK GATE		LOWER LOCK GATE		REMARK
			WIDTH	LENGTH	DEPTH	IN M	NO.	TYPE	HEIGHT	TYPE	HEIGHT	
UK	TOWN LOCK	TRENT RIVER	9.1	59	2.6	1.9	1	MITER		MITER		
FRANCE	THE DON LOCK	DEULE CANAL	12.0	138	3.5	2.5	1	SECTOR		SECTOR		
GERMANY	KRIEGENBRUNN	TRANS-EUROPE	12.0	190	4.0		1	VERT. DROP		VERT. RISE		
GERMANY	NUREMBERG-SOUTH	TRANS-EUROPE	12.0	190	4.0	19.5	1	VERT. DROP		VERT. RISE		
GERMANY	LEERSTETTEN	TRANS-EUROPE	12.0	190	4.0	24.7	1	VERT. DROP		VERT. RISE		TYPES TO BE CONFIRMED
GERMANY	KLOZZENBURG	TRANS-EUROPE	12.0	300	4.0		1	MITER		MITER		
HOLLAND	THE TIEL LOCK	AMST.-RHINE	18.0	350	4.2	4.8	1	MITER		VERT. RISE		
USA	EISENHOWER	ST LAWRENCE	24.4	233	9.1	12.8	1	MITER		MITER		
USA	BERTRAND H. SNELL	ST LAWRENCE	24.4	233	9.1	14.9	1	MITER		MITER		
USA	NEW BONNEVILLE LOCK	COLUMBIA-SNAKE	26.2	206	4.6		1					UNDER CONSTRUCTION
USA	ICE HARBOUR	COLUMBIA-SNAKE	26.2	206	4.6	31.4	1	RADIAL DROP	6.1	VERT. RISE	27.7	
USA	LOWER GRANITE	COLUMBIA-SNAKE	26.2	206	4.6	32.0	1	RADIAL DROP	7.0	MITER	37.5	
USA	JOHN DAY	COLUMBIA-SNAKE	26.2	206	4.6	34.4	1	VERT. DROP	8.1	VERT. RISE	34.4	
USA	GAINESVILLE LOCK	TENN.-TOMBIGBEE	33.5	183	3.7	9.8	1	MITER		MITER		
USA	BAY SPRING LOCK	TENN.-TOMBIGBEE	33.5	183	3.7	25.6	1	MITER		MITER		
USA	LOCK NO 1	UPP. MISSISSIPPI	33.5	183	2.7		1	MITER		MITER		HIGH LIFT
USA	LOCK NO 27	UPP. MISSISSIPPI	33.5	366	2.7		1	MITER		MITER		
USA	KEOKUK LOCK	UPP. MISSISSIPPI	33.5	366	2.7		1	MITER		MITER		
USA	MEL PRICE LOCK	UPP. MISSISSIPPI	33.5	366	2.7		1					
USA	WILLOW ISLAND LOCK	OHIO	33.5	366	2.7		1					
USA	OLMSTED LOCK	OHIO	33.5	366	2.7		1					DESIGN STAGE
PANAMA	PEDRO MIGUEL LOCK	PANAMA	33.5	305	12.8	9.2	1	MITER	24.1	MITER	24.1	
PANAMA	MIRAFLORES LOCK	PANAMA	33.5	305	12.8	16.7	2	MITER	23.5	MITER	25.0	
PANAMA	GATUN LOCK	PANAMA	33.5	305	12.8	25.9	3	MITER	23.5	MITER	23.7	
ARGENTINA	YACIRETA DAM	RIO DE PARANA	27.0	270	3.7	24.0	1	VERT. DROP		MITER		

Table 4.2.3 Lock Gates for Canal Locks

NAME OF LOCK	NAME OF RIVER OR CANAL	LOCK IN M		WATER	LIFT	LOCK GATE TYPE	
		LENGTH	WIDTH	DEPTH	IN M	UPPER	LOWER
LEERSTETTEN	TRANS-EUROPE	190	12.0	4.0	24.7	DROP	RISE
JOHN DAY	COLUMBIA-SNAKE	206	26.2	4.6	34.4	DROP	RISE
YACIRETA DAM	RIO DE PARANA	270	27.0	3.7	24.0	DROP	SWING
BAY SPRING LOCK	TENN.-TOMBIGBEE	183	33.5	3.7	25.6	SWING	SWING
TOWN LOCK	TRENT RIVER	59	9.1	2.6	1.9	SWING	SWING
THE DON LOCK	DEULE CANAL	138	12.0	3.5	2.5	SWING	SWING
THE TIEL LOCK	AMST.-RHINE	350	18.0	4.2	4.8	SWING	RISE
BERTRAND H. SNELL	ST LAWRENCE	233	24.4	9.1	14.9	SWING	SWING
LOCK NO 27	UPP. MISSISSIPPI	366	33.5	2.7		SWING	SWING
GATUN LOCK	PANAMA	305	33.5	12.8	25.9	SWING	SWING

Comparison of the Existing Lock and Others

5 cases were chosen from the previously listed locks to make comparisons with the existing lock. The results are shown on Table 4.2.4.

Table 4.2.4 Comparison of Lock

Comparison Item		Panama	Bertrand H.Snell	Leers-tetten	Bay Spring	Leith	Beren-drecht
Navigation Lock		○	○	○	○		
Entrance Lock						○	○
Year of Completion		1913	1959	1974?	1985	1969	1987
Length in Meter		305	233	190	183	259	500
Width in Meter		33.5	24.4	12	33.5	33.5	68
Lift	in Meter	25.9	14.9	24.7	25.8		5.25
	Number	3	1	1*	1	1	1
Lock Gate Protection	Guard Gate	Yes	No	No	No	No	Yes
	Safety Gate	Yes	No	No	No	No	Yes
Lock Gate Type	Miter	○	○		○		
	Slide					○	○
	Vertical			○			
Culvert Gate	Stoney	○					
	Reverse Radial		○		○	○	○
Emergency Gate		Yes	No	No	No	No	No

Note 1.* shows provision of water saving locks

(2) General Hydraulic Conditions for Gate Design

General Hydraulic Conditions for various gate designs are shown on Table 4.2.5 whose content conforms to the water levels of design criteria given in Chapter 1 except as noted.

Table 4.2.5 Required Water Levels

Location	Water Level	H.W.L.	L.W.L.
Gatun Lake	Rise	Rise+0.6m	Rise-0.9m
Atlantic Coast	+0.1 P.L.D.	+0.5m	-0.3m
Pacific Coast	+0.3 P.L.D	+3.3m	-2.7m

Note 1. For water elevations in the upper chambers of 2 lift type locks, the mean value of the Gatun standard elevation and the respective ocean's standard elevation is taken for the Phase 1 study. Optimization of these elevations with respect to either construction cost or water consumption will be left for Phase 2.

2. The Emergency Gate will be designed for Gatun Lake H.W.L. plus 1.5m (approx.=5').

3. Hydraulic conditions for the design of Tidal Gates will conform to those given in IOCS Memorandum JAX 67.

4. Freeboard; as given in Table 4.2.6.

Table 4.2.6 Freeboard Allowances

Gate Name	Meter	Feet
Lock Gate	0.6	2*
Emergency Gate	0	0
Maintenance Gate	0.6	2*
Tidal Gates	0.6	2

Note 1: Marked value corresponds to the one used in Deep Draft Lock Plan Study in IOCS memorandum JAX 103.

(3) Structural Materials and their Allowable Stress Levels

a) Proposed Materials

Structural materials proposed for the purpose of this study are the usual carbon or low alloy carbon steels having good weldability, good notch ductility and high resistance to brittle fracture. Steels which can be classified in this category are widely available in mill markets now. The proposed strength range is up to 100 kg/mm2 in fracture strength. Preference will be given to quenched and tempered steels in case of high tensile strength steel (high-tension steel abbreviated as H.T. steel).

b) Allowable Stress Levels

Failure Mode: Yielding

The allowable stress levels used in the study are those of the "Technical Standards for Gates and Penstocks" edited by the Hydraulic Gate and Penstock Association in Japan. Table 4.2.7 shows allowable values for tensile and compressive stresses for various strength grades. The values shown are only for examples and applicable for the thicker plates than 40 mm.

Table 4.2.7 Allowable Stresses

Strength level	Yield P. kg/mm2	Fracture P. kg/mm2	Allowable Stress kg/mm2
SS400	22	41	11.0
SM400	22	41	11.0
SM490	30	50	15.0
SM570	43	58	20.4
H.T.70	60	70	26.0
H.T.80	70	80	29.1
H.T.100	90	97	34.6

Failure Mode: Fatigue

The duration life of the gates is assumed to be 50 years. Table 4.2.8 shows the number of lock operations over the design life calculated for various operation frequency levels:

Table 4.2.8 Number of Lock Operations

Frequency	Number of Operations	
Class	Per Year	Per 50 Years
A	15,000	750,000
B	20,000	1,000,000
C	25,000	1,250,000
D	35,000	1,750,000

Note 1. Number of operations means number of gate operations and differs from number of transits in general.

Allowable stresses for prevention of Fatigue failure for each frequency class established on the previous page are shown in Table 4.2.9. These values were derived from the latest edition (1989) of Fatigue Design Guide issued by the Japanese Society of Steel Construction (JSSC). The study works for this edition have included comparison of stress levels with various technical standards including AASHTO, BS5400 and ECCS.

The values in the shaded area in the table have been adopted for the study this time. The frequency of lock operations per year in this area corresponds to approximately 4 times the capacity of new locks at Gatun shown on Section Annex. 2.11.1 on this Final Report say, 36 standard ships per day for two lanes in the relay operation.

The values derived are based on the condition that inspections for fatigue damage and estimation of the remaining life are carried out periodically.

Table 4.2.9 Allowable Stress for Fatigue Design

Load Frequency Class	Class A	Class B	Class C	Class D
Frequency of Operation Per Year	15,000	20,000	25,000	35,000
Tension				
Mother Metal	21.9	19.9	18.8	16.5
Finished Butt & Seam Joint	21.9	19.9	18.5	16.5
Fillet Weld Joint in Load Direction	17.7	16.1	14.9	13.3
Fillet Weld Joint in Normal Direction	14.2	12.9	11.9	10.7
Compression				
Mother Metal	28.5	25.9	24.0	21.5
Finished Butt & Seam Joint	28.5	25.9	24.0	21.5
Fillet Weld Joint in Load Direction	23.0	20.9	19.4	17.3
Fillet Weld Joint in Normal Direction	18.4	16.7	15.5	13.9

Note 1. The allowable stresses shown are in Kg/mm2

c) Failure Mode to be Considered for Each Gate

Failure modes to be considered for each gate are shown on Table 4.2.10.

Table 4.2.10 Failure Mode Application

Failure	Gate Type				
Mode	Lock G.	Culvert G.	Emergency G.	Maintenance G.	Tidal G.
Yielding	Yes	Yes	Yes	Yes	Yes
Fatigue	Yes	Yes	No	No	No

d) Corrosion protection

Both paint coatings and electric corrosion protection systems are proposed to reduce corrosion progression on metal works. Application of electric corrosion protection system are also discussed on each gate at the next section. Further concrete discussion will be made at the Phase 2 study.

(4) Weight Estimation Procedure

a) Gate Leaves

All major factors which may control unit weights (ton/m2) of gate leaves were listed up for each gate type and the factor which seemed to have most effect on the leaf unit weight was selected from them. Table 4.2.11 shows the unit weight control factors which were selected for each type of gate.

Table 4.2.11 Weight Control Factor

Lock G.	Culvert G.	Emergency G.	Maintenance G.	Tidal G.
L x Pmean	Pc x H	L x H	L x P x P/H	P2/3 x H4/3 x (1-2/5xα)

Note 1. L=Lock width (m), H=Gate height (m),
Pmean= Mean design pressure (ton/m2),
Pc= Pressure at leaf center (ton/m2),
P= Maximum Pressure (ton/m2),
α= P/H

Fig. 4.2.1 shows unit weights of various Lock Gates against the selected weight control factor. The fact that unit weights of the existing Panama Lock Gates (Status Quo, SQ) almost follow a line on the graph demonstrates the validity of the factor selection. Unit weights obtained from the Anderson Report for the Deep Draft Lock Canal are also shown (DDL).

The next step was selection of model cases for preliminary designs. The three model cases shown on the figure were so selected that their weight control factors would cover the whole range of weight control factors for all the study cases. Preliminary designs were carried out on the selected model cases and their unit weights were plotted on the figure. Unit weights for all study cases (S.C.) were then determined from the graph such that they would plot in the curve which was defined by the three points of the model cases. Fig. 4.2.2. shows total leaf weights plotted against a factor which relates to the magnitude of bending moments in the gate leaves. This graph demonstrates that the total Leaf weights adopted for the various study cases are also reasonable compared to existing Panama Lock (SQ), Deep Draft Lock (DDL), and the model cases (MODEL).

Table 4.2.12 is the numerical data on which Fig. 4.2.1 and Fig. 4.2.2 are based.

Fig. 4.2.3 shows unit weights of Culvert Gates, Fig. 4.2.4 Emergency Gates, Fig 4.2.5 Maintenance Gates and Fig. 4.2.6 Tidal Gates.

Fig. 4.2.7 shows total leaf weights of Tidal Gates plotted against a factor which relates to bending moments yielding in frames supporting the skin plates of the gate surfaces.

All gates were treated in the same manner to get unit weights but preliminary designs based on model cases were only developed for the Lock Gates. The unit weights for other gate types were determined based upon weight data given in the Anderson Report or from other fabrication record sources, whose project names appear on these figures.

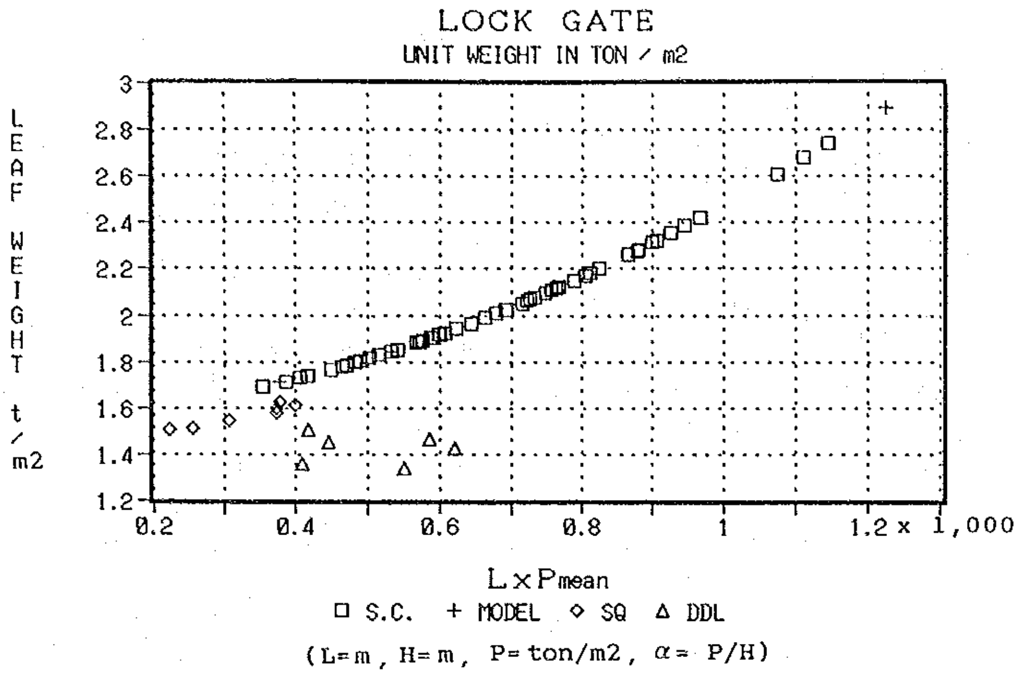


Fig. 4.2.1 Lock Gate Unit Weight

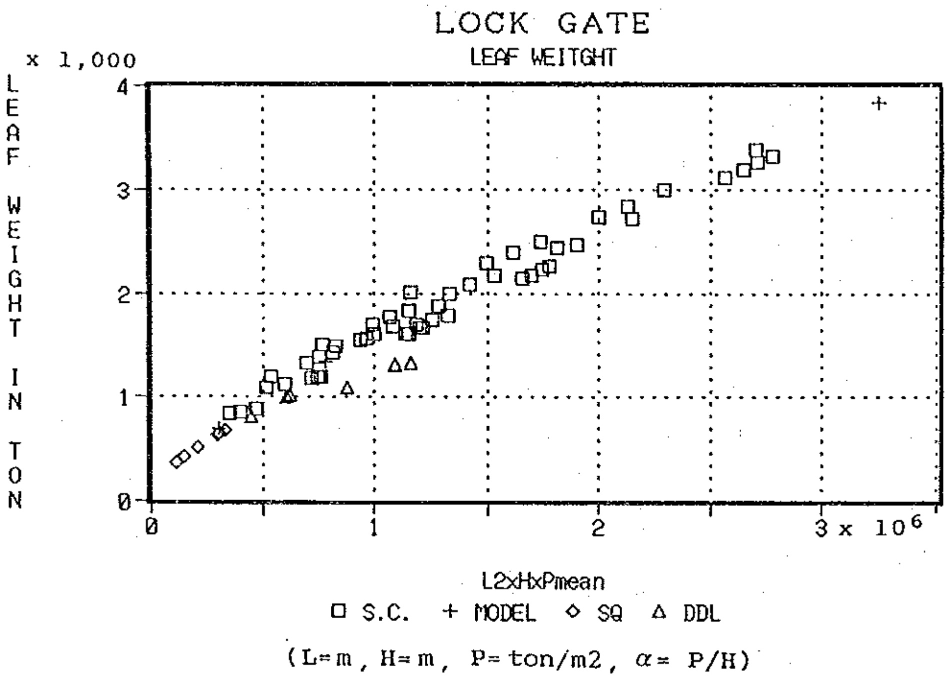


Fig. 4.2.2 Lock Gate Total Weight

Table 4.2.12 Lock Gate Weight Data

GATE IDENTIFICATION		Lx	GATE		UNIT WEIGHT (TON/m2)				TOTAL WEIGHT (TON)			
GROUP	NUMBER/NAME	Pmean	H	L	SQ	DDL	D.M.	S.C.	SQ	DDL	D.M.	S.C.
STATUS QUO (S.Q.)	GATUN UPP. GUARD	254	16.7	33.5	1.510				422			
	GATUN UPP. OPE.	372	23.7	33.5	1.581				629			
	PEDRO UPP. OPE.	378	24.1	33.5	1.623				655			
	MIRA. GUARD GATE	221	14.4	33.5	1.508				365			
	MIRA. UPP. OPE.	373	23.5	33.5	1.596				628			
	MIRA. LOWER OPE.	399	25.0	33.5	1.613				676			
	MIRA. LOWER GUARD	306	20.1	33.5	1.544				521			
DEEP DRAFT LOCK PLAN (DDL)	150000-UPP. LOCK	416	21.9	48.8		1.506				806		
	150000-MID. LOCK	408	30.5	48.8		1.360				1011		
	150000-LOW. LOCK	446	28.7	48.8		1.449				1012		
	250000-UPP. LOCK	585	26.5	56.4		1.468				1098		
	250000-MID. LOCK	550	35.1	56.4		1.337				1321		
	250000-LOW. LOCK	619	33.2	56.4		1.426				1335		
DESIGN MODEL (D.M.)	LARGEST CASE	1223	42.1	63.0			2.897				3841	
	MIDDLE CASE	533	29.9	48.8			1.845				1346	
	SMALLEST CASE	378	24.1	33.5			1.709				690	
STUDY CASE (S.C.) PACIFIC SIDE	GL1 M12	465	31.9	47.0				1.781				1335
	GL1 M11	405	21.1	47.0				1.730				858
	GL2 M23	568	35.2	47.0				1.881				1556
	GL2 M22	748	32.8	47.0				2.096				1615
	GL2 M21	482	21.1	47.0				1.796				891
	GL3 M23	592	36.0	47.0				1.907				1614
	GL3 M22	768	33.5	47.0				2.123				1671
	GL3 M21	482	21.1	47.0				1.796				891
	GL4 M12	693	39.4	47.0				2.025				1875
	GL4 M11	481	21.1	47.0				1.796				890
	GL5 M12	946	48.4	47.0				2.387				2715
	GL5 M11	482	21.1	47.0				1.796				891
	GL6 M12	542	33.9	54.0				1.854				1697
	GL6 M11	483	23.1	54.0				1.797				1121
	GL7 M23	663	37.2	54.0				1.988				1997
	GL7 M22	900	34.8	54.0				2.315				2175
	GL7 M21	608	23.1	54.0				1.924				1200
	GL8 M23	691	38.0	54.0				2.023				2075
	GL8 M22	926	35.5	54.0				2.355				2257
	GL8 M21	608	23.1	54.0				1.924				1200
	GL9 M12	810	41.4	54.0				2.180				2437
	GL9 M11	599	23.1	54.0				1.914				1194
	GL10 M12	644	36.9	63.0				1.965				2284
	GL10 M11	588	26.1	63.0				1.903				1564
	GL11 M23	789	40.2	63.0				2.151				2724
	GL11 M22	1112	37.8	63.0				2.678				3189
	GL11 M21	803	26.1	63.0				2.171				1785
	GL12 M23	823	41.0	63.0				2.200				2841
	GL12 M22	1146	38.5	63.0				2.743				3326
	GL12 M21	803	26.1	63.0				2.171				1785
	GL13 M12	965	44.4	63.0				2.419				3384
	GL13 M11	763	26.1	63.0				2.116				1739
STUDY CASE (S.C.) ATLANTIC SIDE	GL1 M12	386	29.5	47.0				1.715				1189
	GL1 M11	353	21.1	47.0				1.690				838
	GL2 M23	490	32.7	47.0				1.804				1386
	GL2 M22	734	32.9	47.0				2.077				1606
	GL2 M21	482	21.1	47.0				1.796				891
	GL3 M23	515	33.5	47.0				1.828				1439
	GL3 M22	757	33.6	47.0				2.107				1664
	GL3 M21	482	21.1	47.0				1.796				891
	GL4 M12	622	37.0	47.0				1.941				1687
	GL4 M11	471	21.1	47.0				1.786				886
	GL5 M12	880	46.0	47.0				2.284				2469
	GL5 M11	482	21.1	47.0				1.796				891
	GL6 M12	449	31.5	54.0				1.767				1503
	GL6 M11	417	23.1	54.0				1.740				1085
	GL7 M23	572	34.7	54.0				1.885				1766
	GL7 M22	877	34.9	54.0				2.279				2147
	GL7 M21	608	23.1	54.0				1.924				1200
	GL8 M23	601	35.5	54.0				1.917				1837
	GL8 M22	906	35.6	54.0				2.324				2234
	GL8 M21	608	23.1	54.0				1.924				1200
	GL9 M12	727	39.0	54.0				2.067				2177
	GL9 M11	576	23.1	54.0				1.890				1179
	GL10 M12	533	34.5	63.0				1.845				2005
	GL10 M11	503	26.1	63.0				1.816				1493
	GL11 M23	680	37.7	63.0				2.008				2385
	GL11 M22	1075	37.9	63.0				2.609				3115
	GL11 M21	803	26.1	63.0				2.171				1785
	GL12 M23	715	38.5	63.0				2.053				2489
	GL12 M22	1112	38.6	63.0				2.679				3257
	GL12 M21	803	26.1	63.0				2.171				1785
	GL13 M12	866	42.0	63.0				2.262				2993
	GL13 M11	722	26.1	63.0				2.062				1695

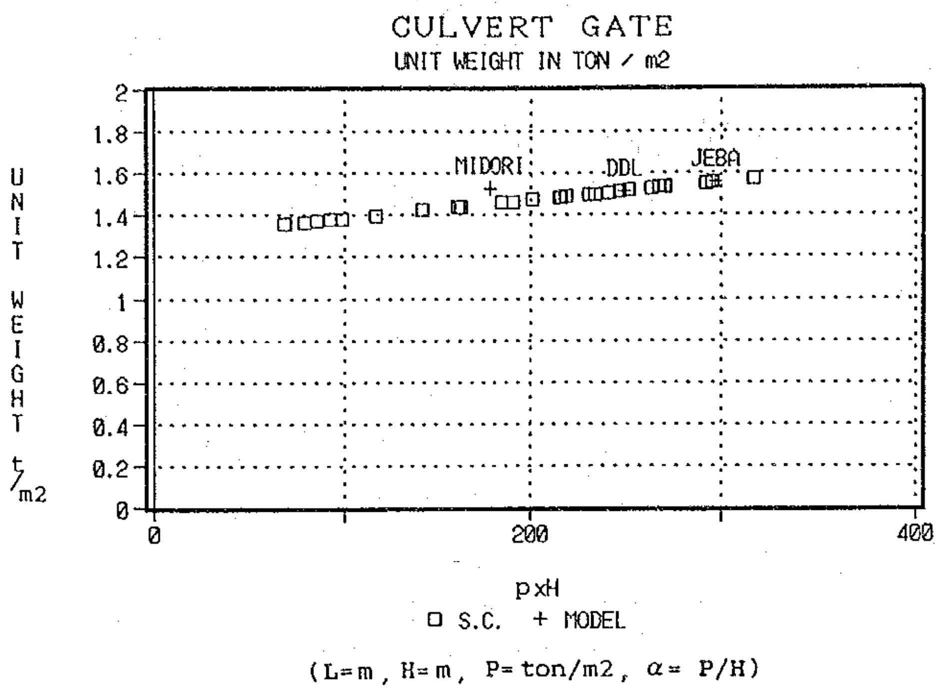


Fig. 4.2.3 Culvert Gate Unit Weight

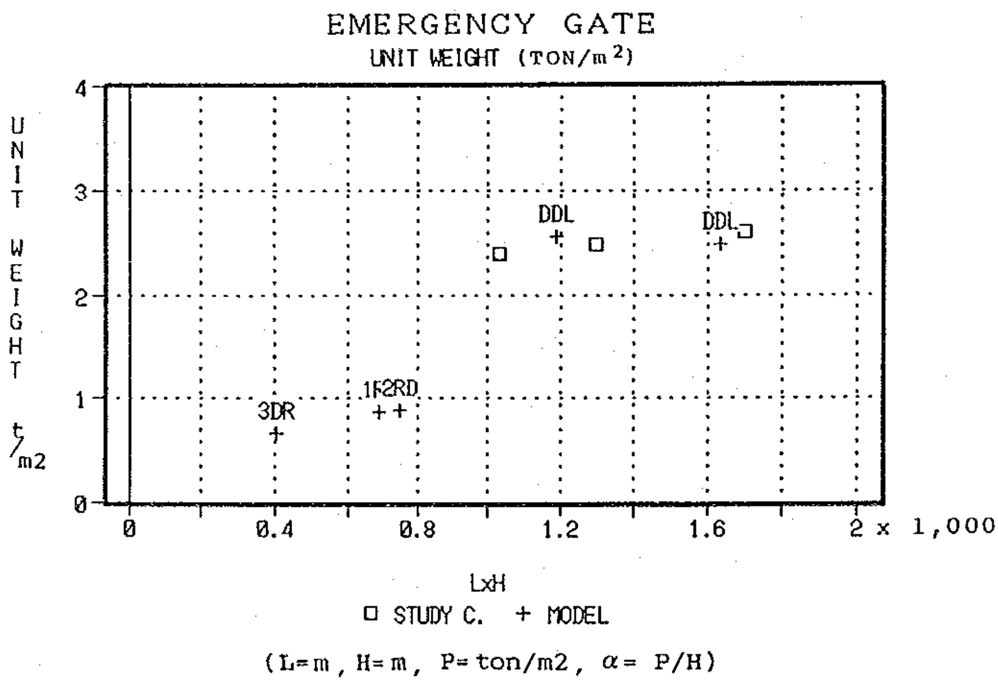
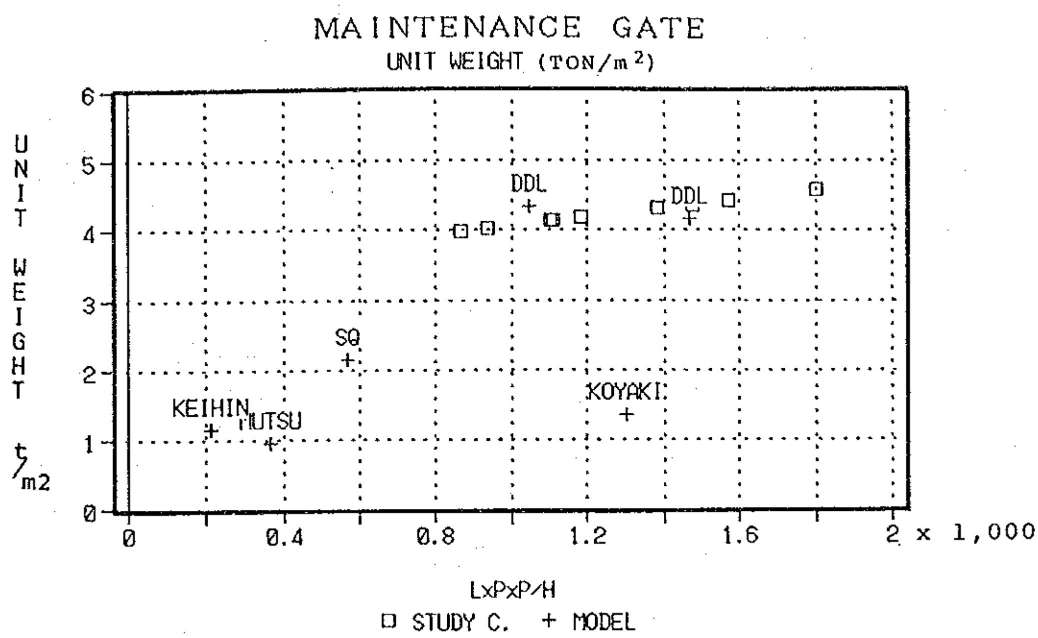
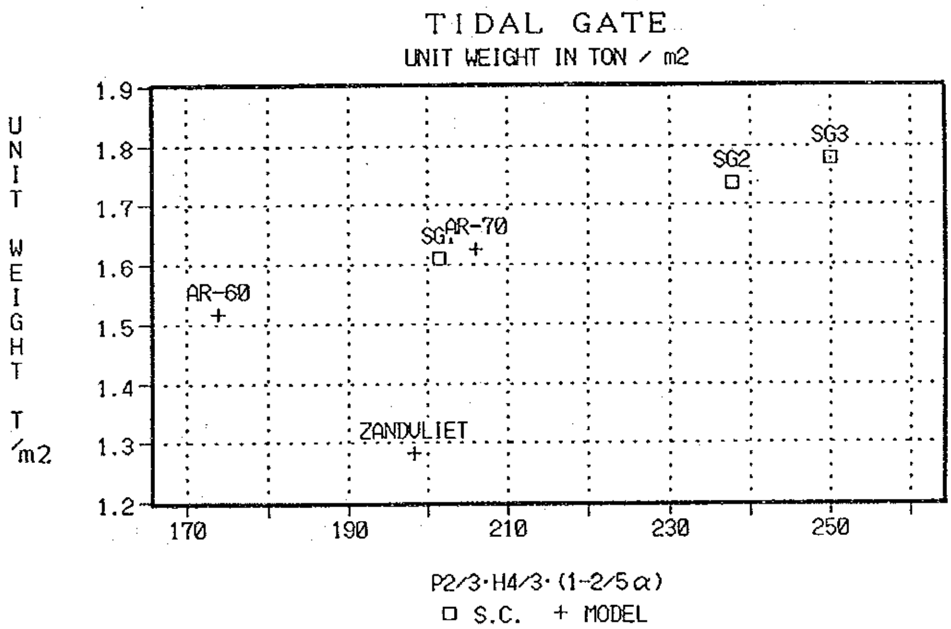


Fig.4.2.4 Emergency Gate Unit Weight



(L=m, H=m, P=ton/m2, α= P/H)

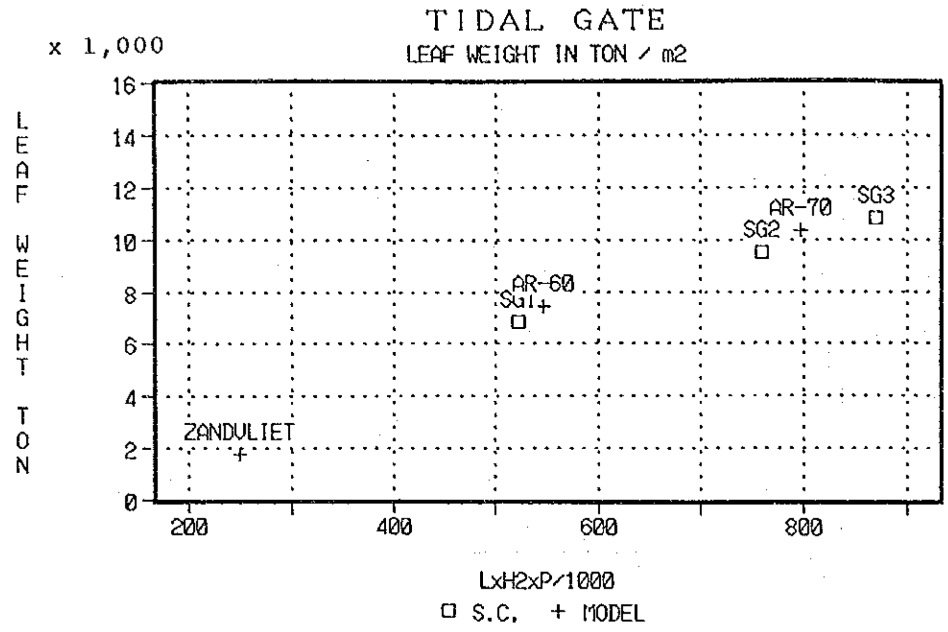
Fig. 4.2.5 Maintenance Gate Unit Weight



(L=m, H=m, P=ton/m2, α= P/H)

Note 1. Gate name
Ar; Anderson Reports, 60; Gate Height in feet

Fig. 4.2.6 Tidal Gate Unit Weight



(L=m, H=m, P=ton/m2, α= P/H)

Fig. 4.2.7 Tidal Gate Total Weight

b) Gate Frames and Drive Mechanisms

Weights of gate frames and drive mechanisms have been derived based upon the corresponding leaf weights. Table 4.2.13 shows the weights of gate frames and drive mechanisms as a ratio of their leaf weights. These values were established only estimating cost for the purposes of this study.

Table 4.2.13 Factors for Weight Estimation

Part	Lock G.	Culvert G.	Emergency G.	Maintenance G.	Tidal G.
Gate Frame	0.2	0.8	0.4	0.1	0.15
Drive Mecha.	0.15	0.6	0.15	0.09	0.1

(5) Fabrication

All gates except Culvert Gates are fabricated at shops as a whole either in open yards or docks and Culvert Gates are fabricated according to conventional methods.

(6) Transportation

Culvert Gate sections are packed and shipped in a conventional way and all other gates are towed either on barges or floated according to their shapes and dimensions.

(7) Installation

Culvert Gates are erected in place according to conventional methods, say by a truck crane, a tower crane or other available means. All other gates are set in place using a floating crane according to the steps shown in Fig. 4.2.8 Elimination of overhaul outage of locks after they start working was one of the main themes in the study of The Third Lock Plan and the gate should be ready to work as soon as it is set in place (Just Set In Place Installation). To realize this, seal mechanisms, bearing systems, support systems etc. which are usually under water must be able to adapt themselves to bigger dimensional deviations in gate leaves and embedded metals than ordinary gate designs. Just Set In Place Installation is one of the important ideas of the conceptual design. However, all parts under water should also be adjustable in drained conditions.

4.2.2 Results of Conceptual Designs

(1) Lock Gates

a) Gate Type and Structural System

On Table 4.6.1, various gate types are compared with respect to important technical or economical elements relevant to Lock Gates. Although the best evaluation result was given to gate type No. 11 (torsion type rolling gate), the gate type proposed here is the Miter Gate that has worked without any major defects in the Panama Canal locks since the canal was constructed. The structure system is a box type supported along vertical ends.

Fig. 4.2.9 shows a general view of the proposed Lock Gates. The gate leaf is supported by embodiments in concrete work at two points; i.e. at the top corner of the leaf by a gudgeon pin and at the bottom corner of the leaf by a pintle. The leaf weight is supported by the pintle and moment occurring due to the difference of the leaf weight center and the pintle reaction force center is supported by a pulling force on the gudgeon pin and pushing force of the pintle. Water pressure acting upon the shell plate of the box type leaf is supported by bearing blocks arranged along the quoin end and the miter end of the gate leaf. There are no supports along the bottom sill except two emergency stops; i.e. one located around the miter end for the leaf over-run and the other located around the quoin end for the pintle slip.

b) Hydraulic Conditions for Pre-Screening Design

The hydraulic conditions to be adopted for the design of Lock Gates is the critical condition which can occur under natural conditions. This is a combination of the highest up-stream water elevation in front of each gate and the lowest sea level of the corresponding ocean.

c) Materials

All levels of structural steel to be considered are listed in Table 4.2.7.

Notwithstanding the above, it is predicted that all parts whose failure mode is classified as Fatigue will be composed of steels of up to SM570 level shown in the table.

d) Numerical Results of Conceptual Design

Table 4.2.14 shows results of Lock Gates for the Pacific side and Table 4.2.15 shows results for the Atlantic side.

Table 4.2.14 Design Results for Lock Gates on Pacific Side

CASE	LOCK GATE	WIDTH	LEAF HEIGHT	DESIGN HD		ESTIMATED WEIGHT IN TON			
				UP-S	DOWN	LEAF	GFRAME	MACH.	TOTAL
L-1	UPPER	47	21.1	20.5	0.0	891	178	134	1,203
L-1	MIDDLE	47	33.5	32.9	2.6	1,671	334	251	2,256
L-1	LOWER	47	36.0	35.4	19.0	1,614	323	242	2,179
L-2	UPPER	47	21.1	20.5	0.0	891	178	134	1,203
L-2	MIDDLE	47	32.8	32.2	3.4	1,615	323	242	2,180
L-2	LOWER	47	35.2	34.6	19.0	1,556	311	233	2,100
L-2'	UPPER	47	21.1	20.5	0.0	891	178	134	1,203
L-2'	LOWER	47	48.4	47.8	19.0	2,715	543	407	3,665
L-3	UPPER	47	21.1	20.5	0.7	890	178	134	1,202
L-3	LOWER	47	39.4	38.8	19.0	1,875	375	281	2,531
L-4	UPPER	54	23.1	22.5	0.0	1,200	240	180	1,620
L-4	MIDDLE	54	35.5	34.9	4.6	2,257	451	339	3,047
L-4	LOWER	54	38.0	37.4	21.0	2,075	415	311	2,801
L-5	UPPER	54	23.1	22.5	0.0	1,200	240	180	1,620
L-5	MIDDLE	54	34.8	34.2	5.4	2,175	435	326	2,936
L-5	LOWER	54	37.2	36.6	21.0	1,997	399	300	2,696
L-6	UPPER	54	23.1	22.5	2.7	1,194	239	179	1,612
L-6	LOWER	54	41.4	40.8	21.0	2,437	487	366	3,290
L-7	UPPER	63	26.1	25.5	0.0	1,785	357	268	2,410
L-7	MIDDLE	63	38.5	37.9	7.6	3,326	665	499	4,490
L-7	LOWER	63	41.0	40.4	24.0	2,841	568	426	3,835
L-8	UPPER	63	26.1	25.5	0.0	1,785	357	268	2,410
L-8	MIDDLE	63	37.8	37.2	8.4	3,189	638	478	4,305
L-8	LOWER	63	40.2	39.6	24.0	2,724	545	409	3,678
L-9	UPPER	63	26.1	25.5	5.7	1,739	348	261	2,348
L-9	LOWER	63	44.4	43.8	24.0	3,384	677	508	4,569
L-10	UPPER	47	21.1	20.5	0.0	891	178	134	1,203
L-10	MIDDLE	47	32.8	32.2	3.4	1,615	323	242	2,180
L-10	LOWER	47	35.2	34.6	19.0	1,556	311	233	2,100
L-11	UPPER	47	21.1	20.5	0.7	890	178	134	1,202
L-11	LOWER	47	39.4	38.8	19.0	1,875	375	281	2,531
L-12	UPPER	47	21.1	20.5	8.2	858	172	129	1,159
L-12	LOWER	47	31.9	31.3	19.0	1,335	267	200	1,802
L-13	UPPER	54	23.1	22.5	0.0	1,200	240	180	1,620
L-13	MIDDLE	54	34.8	34.2	5.4	2,175	435	326	2,936
L-13	LOWER	54	37.2	36.6	21.0	1,997	399	300	2,696
L-14	UPPER	54	23.1	22.5	2.7	1,194	239	179	1,612
L-14	LOWER	54	41.4	40.8	21.0	2,437	487	366	3,290
L-15	UPPER	54	23.1	22.5	10.2	1,121	224	168	1,513
L-15	LOWER	54	33.9	33.3	21.0	1,697	339	255	2,291
L-16	UPPER	63	26.1	25.5	0.0	1,785	357	268	2,410
L-16	MIDDLE	63	37.8	37.2	8.4	3,189	638	478	4,305
L-16	LOWER	63	40.2	39.6	24.0	2,724	545	409	3,678
L-17	UPPER	63	26.1	25.5	5.7	1,739	348	261	2,348
L-17	LOWER	63	44.4	43.8	24.0	3,384	677	508	4,569
L-18	UPPER	63	26.1	25.5	13.2	1,564	313	235	2,112
L-18	LOWER	63	36.9	36.3	24.0	2,284	457	343	3,084

Note 1. Width, Height and Design Head are shown in m.

Table 4.2.15 Design Results for Lock Gates on Atlantic Side

CASE	LOCK GATE	WID-TH	LEAF HEIGHT	DESIGN HD		ESTIMATED WEIGHT IN TON			
				UP-S	DOWN	LEAF	GFRAME	MACH.	TOTAL
L - 1	UPPER	47	21.1	20.5	0.0	891	178	134	1,203
L - 1	MIDDLE	47	33.6	33.0	5.1	1,664	333	250	2,247
L - 1	LOWER	47	33.5	32.9	19.0	1,439	288	216	1,943
L - 2	UPPER	47	21.1	20.5	0.0	891	178	134	1,203
L - 2	MIDDLE	47	32.9	32.3	5.9	1,606	321	241	2,168
L - 2	LOWER	47	32.7	32.1	19.0	1,386	277	208	1,871
L - 2'	UPPER	47	21.1	20.5	0.0	891	178	134	1,203
L - 2'	LOWER	47	46.0	45.4	19.0	2,469	494	370	3,333
L - 3	UPPER	47	21.1	20.5	3.1	867	177	133	1,177
L - 3	LOWER	47	37.0	36.4	19.0	1,687	337	253	2,277
L - 4	UPPER	54	23.1	22.5	0.0	1,200	240	180	1,620
L - 4	MIDDLE	54	35.6	35.0	7.1	2,234	447	335	3,016
L - 4	LOWER	54	35.5	34.9	21.0	1,837	367	276	2,480
L - 5	UPPER	54	23.1	22.5	0.0	1,200	240	180	1,620
L - 5	MIDDLE	54	34.9	34.3	7.9	2,147	429	322	2,898
L - 5	LOWER	54	34.7	34.1	21.0	1,766	353	265	2,384
L - 6	UPPER	54	23.1	22.5	5.1	1,179	236	177	1,592
L - 6	LOWER	54	39.0	38.4	21.0	2,177	435	327	2,939
L - 7	UPPER	63	26.1	25.5	0.0	1,785	357	268	2,410
L - 7	MIDDLE	63	38.6	38.0	10.1	3,257	651	489	4,397
L - 7	LOWER	63	38.5	37.9	24.0	2,489	498	373	3,360
L - 8	UPPER	63	26.1	25.5	0.0	1,785	357	268	2,410
L - 8	MIDDLE	63	37.9	37.3	10.9	3,115	623	467	4,205
L - 8	LOWER	63	37.7	37.1	24.0	2,385	477	358	3,220
L - 9	UPPER	63	26.1	25.5	8.1	1,695	339	254	2,288
L - 9	LOWER	63	42.0	41.4	24.0	2,993	599	449	4,041
L - 10	UPPER	47	21.1	20.5	0.0	891	178	134	1,203
L - 10	MIDDLE	47	32.9	32.3	5.9	1,606	321	241	2,168
L - 10	LOWER	47	32.7	32.1	19.0	1,386	277	208	1,871
L - 11	UPPER	47	21.1	20.5	3.1	886	177	133	1,196
L - 11	LOWER	47	37.0	36.4	19.0	1,687	337	253	2,277
L - 12	UPPER	47	21.1	20.5	10.6	838	168	126	1,132
L - 12	LOWER	47	29.5	28.9	19.0	1,189	238	178	1,605
L - 13	UPPER	54	23.1	22.5	0.0	1,200	240	180	1,620
L - 13	MIDDLE	54	34.9	34.3	7.9	2,147	429	322	2,898
L - 13	LOWER	54	34.7	34.1	21.0	1,766	353	265	2,384
L - 14	UPPER	54	23.1	22.5	5.1	1,179	236	177	1,592
L - 14	LOWER	54	39.0	38.4	21.0	2,177	435	327	2,939
L - 15	UPPER	54	23.1	22.5	12.6	1,085	217	163	1,465
L - 15	LOWER	54	31.5	30.9	21.0	1,503	301	225	2,029
L - 16	UPPER	63	26.1	25.5	0.0	1,785	357	268	2,410
L - 16	MIDDLE	63	37.9	37.3	10.9	3,115	623	467	4,205
L - 16	LOWER	63	37.7	37.1	24.0	2,385	477	358	3,220
L - 17	UPPER	63	26.1	25.5	8.1	1,695	339	254	2,288
L - 17	LOWER	63	42.0	41.4	24.0	2,993	599	449	4,041
L - 18	UPPER	63	26.1	25.5	15.6	1,493	299	224	2,016
L - 18	LOWER	63	34.5	33.9	24.0	2,005	401	301	2,707

Note 1. Width, Height and Design Head are shown in m.

e) Sealing

Fig. 4.2.10 shows the concept of seal arrangement.

Both sides and the bottom of a gate leaf are sealed by a continuous "J" shaped rubber seal, which is located along the side and bottom edges of the down stream shell plate of the box type leaf.

Dimensions of the rubber section are bigger than usual to give enough self-adjustability necessary for the Just Set In Place Installation method and the bulb portion of the rubber has the correct hardness to prevent excessive deformation in the bulb itself at high water pressure and, at the same time, maintain enough sealing ability at low water pressure.

f) Pintles, Gudgeon and Miter End and Quoin Bearings

Fig. 4.2.11 shows the concept for pintles and gudgeon arrangement and Fig. 4.2.12 shows the concept for miter end and quoin bearings.

The pintle sits rigidly on base metal embedded in the masonry floor and a pintle bush mounted on the leaf bottom is movable in the direction of the gate width.

The gudgeon is set rigidly to gudgeon anchors embedded in the masonry wall and a gudgeon pin mounted rigidly on the leaf top is supported by the gudgeon so that the pin together with gate leaf may move in the direction of the gate width.

As soon as the gate leaf starts supporting the hydraulic load, the total leaf will move towards bearing blocks set on a gate frame embedded on the masonry wall until the bearing blocks mounted on the leaf quoin end hit the bearing blocks of the masonry side. This concept will release the pintle, gudgeon and quoin bearings from strict limitations on deviations from their designed relative positions and enable the Just Set In Place Method to be realized. This idea will also contribute to decreased wear on the quoin bearing blocks.

The gudgeon and the pintle centers should be located in a common vertical axis and the gudgeon center is adjustable after the gate leaf is set in place. The pintle is removed with the gate leaf whenever the leaf is removed for maintenance.

g) Float Tanks

Most spaces in the box type leaf are assigned as float tanks, the buoyancy force of which compensates for the leaf weight so that load on the pintle may be reduced to a large extent during operational conditions.

h) Corrosion Protection

An electric corrosion protection system is proposed to reduce corrosion progression in not only embedded parts but also in the gate leaf itself. It is also very helpful in extending the leaf's fatigue life. But too much voltage will accelerate consumption of the remaining fatigue life and very careful study is necessary for arrangement of the system.

i) Drive Mechanism

Fig. 4.2.13 shows the concept for the drive mechanism for Lock Gates. Hydraulic power cylinders provide the forces necessary to drive the mechanism.

(2) Culvert Gates

a) Gate Type and Structural System

The proposed gate type is the reversed Radial Gate which was proposed at the 3rd Lock Plan and also in the Deep Draft Lock Plan. Fig. 4.2.14

shows the general view of a Culvert Gate. The existing canal locks have Stony sluice gates for the same purpose. Generally, development of the Fixed Wheel Type gates has now made the Stony Type out-dated because of economical and technical reasons, and no consideration was given to this type of gate in the selection. The superiority of the Reversed Radial Gate to the Fixed Wheel Gate for this application is the redacted friction force during leaf operations.

b) Hydraulic Condition for Pre-Screening Design

Hydraulic conditions for the design of Culvert Gates are a combination of the highest lake elevation and the lowest level of the corresponding ocean.

c) Materials

Structural steel to be adopted would be up to the SM490 level listed in Table 4.2.7.

d) Gate Dimensions for Pre-Screening Purpose

Gate dimensions of the Culvert Gate have been determined so that the same filling time as scheduled in the Deep Draft Lock Plan might be maintained. For the 1 lift study cases the filling time is so short that the water in the chamber may boil up too furiously for the locomotive to restrain the transiting ship in the chamber and the filling time should be reviewed during Phase II before finalizing the designs.

Data used in the calculations were for 250,000 DWT ships in the Anderson Report and filling time was 9 minutes with a 3 minute valve time.

e) Sealing

A preference will given to rubber seals for all leaf edges including the leaf bottom.

f) Numerical Results of Conceptual Design

Table 4.2.16 shows results for Culvert Gate.

Table 4.2.16 Design Results for Culvert Gates

	CASE	CULVERT(m)		DESIGN	NO	ESTIMATED WEIGHT IN TON			
		L	H	PRESSURE	RQ	LEAF	GFRAME	MECHA.	TOTAL
P	L－1	7.1	7.6	30.7	16	81.0	64.8	48.6	194.4
A	L－2	7.0	7.5	29.2	16	78.2	62.6	46.9	187.7
C	L－2'	8.3	9.0	29.2	12	114.1	91.3	68.5	273.9
I	L－3	7.5	8.0	20.0	12	86.3	69.0	51.8	207.1
F	L－4	8.1	8.7	30.7	16	107.9	86.3	64.7	258.9
I	L－5	8.0	8.6	29.2	16	104.4	83.5	62.6	250.5
C	L－6	8.5	9.2	20.1	12	114.1	91.3	68.5	273.9
	L－7	9.5	10.3	30.7	16	154.1	123.3	92.5	369.9
	L－8	9.4	10.1	29.2	16	147.7	118.2	88.6	354.5
	L－9	10.0	10.8	20.1	12	160.6	128.5	96.4	385.5
	L－10	7.0	7.5	29.2	16	78.2	62.6	46.9	187.7
	L－11	7.5	8.0	20.0	12	86.3	69.0	51.8	207.1
	L－12	6.4	6.9	12.4	12	60.6	48.5	36.4	145.5
	L－13	8.0	8.6	29.2	16	104.4	83.5	62.6	250.5
	L－14	8.5	9.2	20.1	12	114.1	91.3	68.5	273.9
	L－15	7.3	7.9	12.4	12	79.8	63.8	47.9	191.5
	L－16	9.4	10.1	29.2	16	147.7	118.2	88.6	354.5
	L－17	10.0	10.8	20.1	12	160.6	128.5	96.4	385.5
	L－18	8.6	9.3	12.4	12	111.8	89.4	67.1	268.3
A	L－1	7.1	7.6	28.3	16	80.2	64.2	48.1	192.5
T	L－2	7.0	7.5	26.8	16	77.3	61.8	46.4	185.5
L	L－2'	8.3	9.0	26.8	12	112.7	90.2	67.6	270.5
A	L－3	7.5	8.0	17.7	12	85.3	68.2	51.2	204.7
N	L－4	8.1	8.7	28.3	16	106.6	85.3	64.0	255.9
T	L－5	8.0	8.6	26.8	16	103.1	82.5	61.9	247.5
I	L－6	8.5	9.2	17.7	12	112.6	90.1	67.6	270.3
C	L－7	9.5	10.3	28.3	16	151.9	121.5	91.1	364.5
	L－8	9.4	10.1	26.8	16	145.7	116.6	87.4	349.7
	L－9	10.0	10.8	17.7	12	158.1	126.5	94.9	379.5
	L－10	7.0	7.5	26.8	16	77.3	61.8	46.4	185.5
	L－11	7.5	8.0	17.7	12	85.3	68.2	51.2	204.7
	L－12	6.4	6.9	10.0	12	60.0	48.0	36.0	144.0
	L－13	8.0	8.6	26.8	16	103.1	82.5	61.9	247.5
	L－14	8.5	9.2	17.7	12	112.6	90.1	67.6	270.3
	L－15	7.3	7.9	10.0	12	78.8	63.0	47.3	189.1
	L－16	9.4	10.1	26.8	16	145.7	116.6	87.4	349.7
	L－17	10.0	10.8	17.7	12	158.1	126.5	94.9	379.5
	L－18	8.6	9.3	10.0	12	110.3	88.2	66.2	264.7

g) Drive Mechanism

Hydraulic power cylinders are used to drive the mechanisms.

h) Corrosion Protection

An electric corrosion protection system is proposed to reduce corrosion progression in not only embedded parts but also in the gate leaf itself. The same precaution as cited for the Lock Gate is necessary in studying the system arrangement.

i) Bulkhead Gates for Maintenance

Bulkhead gate slots are provided up-stream and down stream of the Culvert Gate.

(3) Emergency Gates

a) Gate Type and Structural System

Emergency Gates are supposed to close the lock in case of emergency such as fractures or collapses of Lock Gates due to ship collision and prevent the areas surrounding the lock from total disasters or keep intensity of damages due to the accidents as low as possible. Hence the role of Emergency Gates are very important.

The proposed gate type for Emergency Gates is the Drop Type Roller Gate.

Fig. 4.2.15 shows a general view of the Emergency Gate. A gate leaf consists of a box type main girder and vertical girders. Hydraulic loads acting on the skin plate are finally supported by wheels arranged at both ends of the main girder and along the gate bottom edge. Air supply systems are provided in both masonry walls to supply air into a vacant zone under the flow passing over the gate top to avoid harmful vibration during emergency raising of the gate leaf.

The proposed gate type is similar to the one in the Deep Draft Lock plan (DDL) but completely different from the gates (the Emergency Dam) in the existing Panama canal.

The existing Emergency Dam consists of 30 roller gates, six gate guide girders and 30 hoists. All these components have been stored in a very long truss arm similar to the arm of a tower crane. The truss arm with all gate components usually stays on the lock side wall with its direction parallel to the locomotive rails. In the event of an emergency situation, the truss arm rotates by 90 degrees and its tip reaches the lock center wall and is supported there. Then one end of six gate guide girders are set on the lock bottom sill with other ends supported at the truss arms. Finally all 30 roller gates are hoisted down along the gate guide girders.

The proposed emergency gate type is much simpler in mechanism and shorter in operation time than existing emergency gate and it is more reliable and safer than above mentioned existing emergency gate type. Because of the higher reliability of the proposed gate type to the existing emergency gate type, the Guard Gates and the Safety Gates which have been provided in the existing canal have disappeared in our proposal as so did in Deep Draft Lock plan. The Guard Gates and the Safety Gates in the existing Panama canal are the same Miter type as the Operating Gates and are arranged duplicity with the Operation Gate. They are operated together with the opponent Operating Gate and eventually keep the locks being safe. The below figures are number of the Miter gate leaves adopted in the existing Panama canal, DDL, and the New canal. Not withstanding omissions of the Intermediate Gates in DDL and the New canal and the differences in other conditions, total leaf numbers are duly explanatory for the significance of the Emergency Gate proposed.

	Existing	DDL (Three Lifts)	Proposed (Two Lifts)
Operating Gate	36	32	24
Guard Gate	24	0	0
Safety Gate	12	0	0
Intermediate Gate	20	0	0
Total	92	32	24

Note 1. The Figures of DDL were converted to two lanes for the sake of comparison.

b) Hydraulic Conditions for Pre-Screening Design

Hydraulic conditions for the design of Emergency Gates are water head equal to the gate height while down-stream is dry.

c) Materials

Levels of Structural Steel would be adopted from those listed in Table 4.2.7.

d) Numerical Results of Conceptual Design

Table 4.2.17 shows the results for the Emergency Gate. This table is applicable to both the Pacific and Atlantic sides.

Table 4.2.17 Design Results for Emergency Gates

Case Number	Width (m)	Leaf Height (m)	Design Head UP-S (m)	Design Head Down (m)	Estimated Weight in Ton Leaf	Estimated Weight in Ton G Frame	Estimated Weight in Ton Mack	Estimated Weight in Ton Total
L-1	47	22.0	22.0	0.0	2,476	990	371	3,837
L-2	47	22.0	22.0	0.0	2,476	990	371	3,837
L-2'	47	22.0	22.0	0.0	2,476	990	371	3,837
L-3	47	22.0	22.0	0.0	2,476	990	371	3,837
L-4	54	24.0	24.0	0.0	3,210	1,284	481	4,975
L-5	54	24.0	24.0	0.0	3,210	1,284	481	4,975
L-6	54	24.0	24.0	0.0	3,210	1,284	481	4,975
L-7	63	27.0	27.0	0.0	4,428	1,771	664	6,863
L-8	63	27.0	27.0	0.0	4,428	1,771	664	6,863
L-9	63	27.0	27.0	0.0	4,428	1,771	664	6,863
L-10	47	22.0	22.0	0.0	2,476	990	371	3,837
L-11	47	22.0	22.0	0.0	2,476	990	371	3,837
L-12	47	22.0	22.0	0.0	2,476	990	371	3,837
L-13	54	24.0	24.0	0.0	3,210	1,284	481	4,975
L-14	54	24.0	24.0	0.0	3,210	1,284	481	4,975
L-15	54	24.0	24.0	0.0	3,210	1,284	481	4,975
L-16	63	27.0	27.0	0.0	4,428	1,771	664	6,863
L-17	63	27.0	27.0	0.0	4,428	1,771	664	6,863
L-18	63	27.0	27.0	0.0	4,428	1,771	664	6,863

Note: HD=head, UP-S=upstream, Down=downstream, G Frame=Gate Frame

e) Gate Top Configuration

The gate top configuration is determined so that the velocity head of the flow passing over the

f) Sealing

The side and the bottom of a leaf are sealed with J type seal rubbers. In addition to them, an intermediate seal mechanism installed along the canal bottom will decrease the amount of water flowing out from the gap between the gate leaf and the canal bottom during leaf raising.

g) Wheel Arrangement

Main wheels which carry hydraulic loads acting on the gate leaf are arranged on both ends of the main girder and along the gate bottom. In addition, smaller auxiliary guide wheels are also arranged on both ends of each gate leaf so that the huge leaf may travel surely in case of emergency.

h) Float Tank

Two types of float tanks are provided in the leaf. All tanks except one are always empty (permanent type) and the remaining tank will be drained by compressed air in case of emergency. The total the amount of buoyancy will be much more than gate leaf weight. Nevethless, the rising movement of the gate leaf will be controlled mechanically by a driving mechanism. The tank arrangement described may be changed with further information on similar waterway projects in the States.

i) Corrosion Protection

An electric corrosion protection system is proposed to reduce corrosion progression in not only embedded parts but also in the gate leaf itself.

j) Drive Mechanism

A central jack type hoist machine, augmented by fire pump pressure and buoyancy tanks, as recommended in the Deep Draft Lock Plan, is proposed to operate the Emergency Gate.

(4) Maintenance Gates

a) Gate Type and Structural System

Caisson type gates are proposed.

Fig. 4.2.16 shows a general view of the Maintenance Gate.

b) Hydraulic Condition for Design

Pressure side: Maximum sea or lake level
Lock side : Dry condition

c) Materials

Levels of Structural Steel would be adopted from those listed in Table 4.2.3.

d) Numerical Results of Conceptual Design

Recesses for maintenance gates are proposed on the sea side of locks for all study cases. A maintenance gate for the lake side is provided only for the cases where upper lock gates cannot withstand hydraulic pressures during maintenance conditions or where upper lock gate sills are lower than the Maximum sea level.

d) Numerical Results of Conceptual Design

Table 4.2.18 and Table 4.2.19 show the results of the Maintenance Gate sizing for the Pacific coast and the Atlantic coast respectively.

Table 4.2.18 Design Results for Maintenance Gates on Pacific Side

CASE	MAINT. GATE	LEAF		DESIGN HD		ESTIMATED WEIGHT IN TON			
		L	HEIGHT	UP-S	DOWN	LEAF	GFRAME	MACH.	TOTAL
L－1	LOWER	47	26.5	25.0	0.0	4,693	516	464	5,673
L－2	LOWER	47	26.5	25.0	0.0	4,693	516	464	5,673
L－2'	LOWER	47	26.5	25.0	0.0	4,693	516	464	5,673
L－3	UPPER	47	21.1	20.5	0.0	3,637	400	360	4,397
L－3	LOWER	47	26.5	25.0	0.0	4,693	516	464	5,673
L－4	LOWER	54	28.5	27.0	0.0	6,041	664	597	7,302
L－5	LOWER	54	28.5	27.0	0.0	6,041	664	597	7,302
L－6	UPPER	54	23.1	22.5	0.0	4,754	522	470	5,746
L－6	LOWER	54	28.5	27.0	0.0	6,041	664	597	7,302
L－7	UPPER	63	26.1	25.5	0.0	6,634	729	656	8,019
L－7	LOWER	63	31.5	30.0	0.0	8,270	909	818	9,997
L－8	UPPER	63	26.1	25.5	0.0	6,634	729	656	8,019
L－8	LOWER	63	31.5	30.0	0.0	8,270	909	818	9,997
L－9	UPPER	63	26.1	25.5	0.0	6,634	729	656	8,019
L－9	LOWER	63	31.5	30.0	0.0	8,270	909	818	9,997
L－10	LOWER	47	26.5	25.0	0.0	4,693	516	464	5,673
L－11	UPPER	47	21.1	20.5	0.0	3,637	400	360	4,397
L－11	LOWER	47	26.5	25.0	0.0	4,693	516	464	5,673
L－12	UPPER	47	21.1	20.5	0.0	3,637	400	360	4,397
L－12	LOWER	47	26.5	25.0	0.0	4,693	516	464	5,673
L－13	LOWER	54	28.5	27.0	0.0	6,041	664	597	7,302
L－14	UPPER	54	23.1	22.5	0.0	4,754	522	470	5,746
L－14	LOWER	54	28.5	27.0	0.0	6,041	664	597	7,302
L－15	UPPER	54	23.1	22.5	0.0	4,754	522	470	5,746
L－15	LOWER	54	28.5	27.0	0.0	6,041	664	597	7,302
L－16	UPPER	63	26.1	25.5	0.0	6,634	729	656	8,019
L－16	LOWER	63	31.5	30.0	0.0	8,270	909	818	9,997
L－17	UPPER	63	26.1	25.5	0.0	6,634	729	656	8,019
L－17	LOWER	63	31.5	30.0	0.0	8,270	909	818	9,997
L－18	UPPER	63	26.1	25.5	0.0	6,634	729	656	8,019
L－18	LOWER	63	31.5	30.0	0.0	8,270	909	818	9,997

Table 4.2.19 Design Results for Maintenance Gates on Atlantic Side

CASE	MAINT.	LEAF		DESIGN HD		ESTIMATED WEIGHT IN TON			
	GATE	L	HEIGHT	UP-S	DOWN	LEAF	GFRAME	MACH.	TOTAL
L－1	LOWER	47	21.3	19.8	0.0	3,631	399	359	4,389
L－2	LOWER	47	21.3	19.8	0.0	3,631	399	359	4,389
L－2'	LOWER	47	21.3	19.8	0.0	3,631	399	359	4,389
L－3	UPPER	47	21.1	20.5	0.0	3,637	400	360	4,397
L－3	LOWER	47	21.3	19.8	0.0	3,631	399	359	4,389
L－4	LOWER	54	23.3	21.8	0.0	4,735	520	468	5,723
L－5	LOWER	54	23.3	21.8	0.0	4,735	520	468	5,723
L－6	UPPER	54	23.1	22.5	0.0	4,754	522	470	5,746
L－6	LOWER	54	23.3	21.8	0.0	4,735	520	468	5,723
L－7	LOWER	63	26.3	24.8	0.0	6,592	724	652	7,968
L－8	LOWER	63	26.3	24.8	0.0	6,592	724	652	7,968
L－9	UPPER	63	26.1	25.5	0.0	6,634	729	656	8,019
L－9	LOWER	63	26.3	24.8	0.0	6,592	724	652	7,968
L－10	LOWER	47	21.3	19.8	0.0	3,631	399	359	4,389
L－11	UPPER	47	21.1	20.5	0.0	3,637	400	360	4,397
L－11	LOWER	47	21.3	19.8	0.0	3,631	399	359	4,389
L－12	UPPER	47	21.1	20.5	0.0	3,637	400	360	4,397
L－12	LOWER	47	21.3	19.8	0.0	3,631	399	359	4,389
L－13	LOWER	54	23.3	21.8	0.0	4,735	520	468	5,723
L－14	UPPER	54	23.1	22.5	0.0	4,754	522	470	5,746
L－14	LOWER	54	23.3	21.8	0.0	4,735	520	468	5,723
L－15	UPPER	54	23.1	22.5	0.0	4,754	522	470	5,746
L－15	LOWER	54	23.3	21.8	0.0	4,735	520	468	5,723
L－16	LOWER	63	26.3	24.8	0.0	6,592	724	652	7,968
L－17	UPPER	63	26.1	25.5	0.0	6,634	729	656	8,019
L－17	LOWER	63	26.3	24.8	0.0	6,592	724	652	7,968
L－18	UPPER	63	26.1	25.5	0.0	6,634	729	656	8,019
L－18	LOWER	63	26.3	24.8	0.0	6,592	724	652	7,968

f) Sealing

The leaf sides and the tear bottom are sealed by J type rubbers.

g) Float Tank

The leaf has many float tanks in it to adjust draft for various conditions such as positioning on the ocean side, positioning on the lake sides or removing.

h) Corrosion Protection

An electric corrosion protection system is proposed to reduce corrosion progression in embedded parts.

i) Water Filling Valves and Drainage Pumps

Valves and pumps are provided in Maintenance Gates to fill and drain water into or out of the ballast tanks in the gate leaves. This equipment is also used for water in the lock chambers but covers only half the capacity required to fill or drain whole chambers in a 24 hours period. The remaining half capacity is shared by drain pumps provided in the masonry walls on the sea side.

4.2.3 Sketches

(1) General

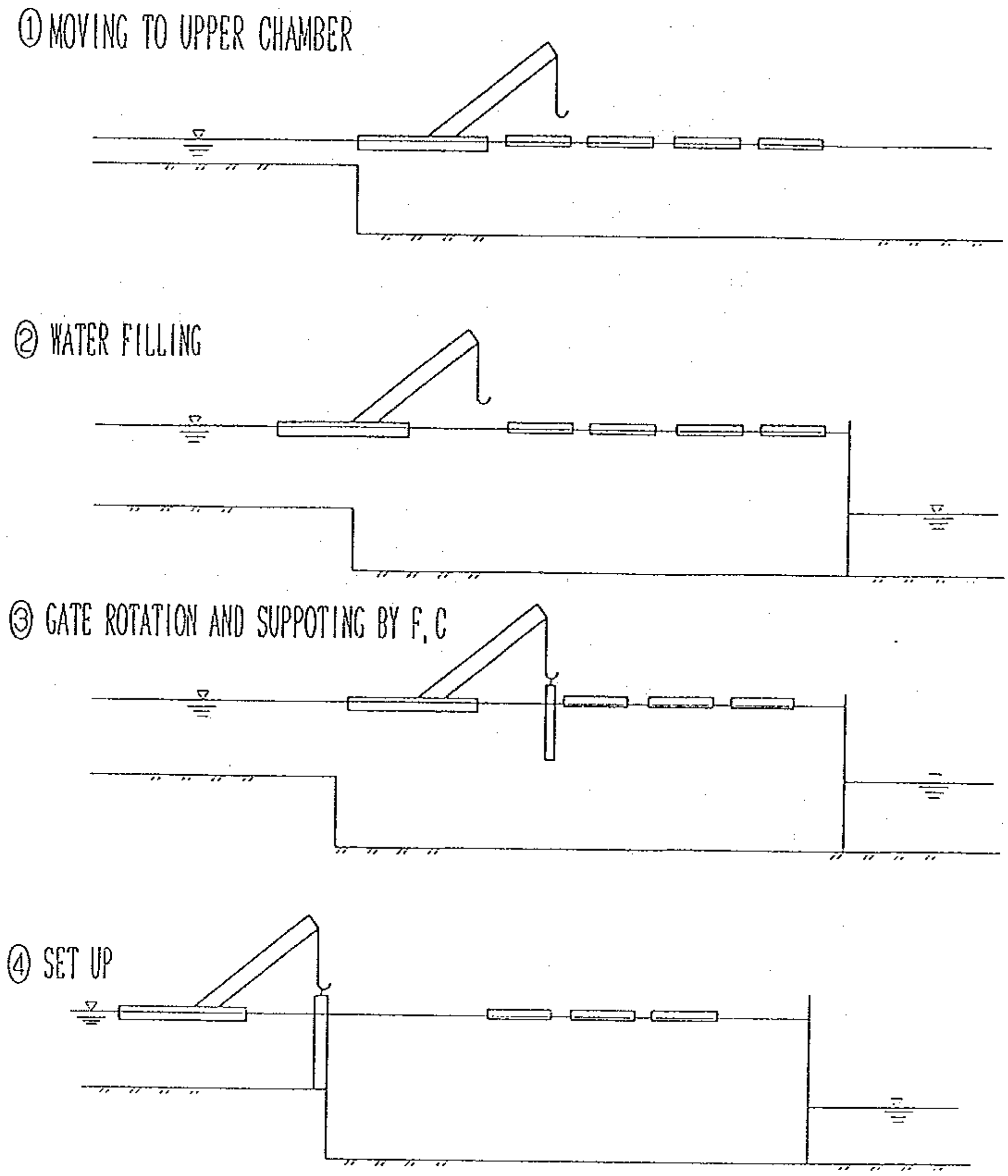


Fig. 4.2.8 Installation Procedure

(2) Lock Gates

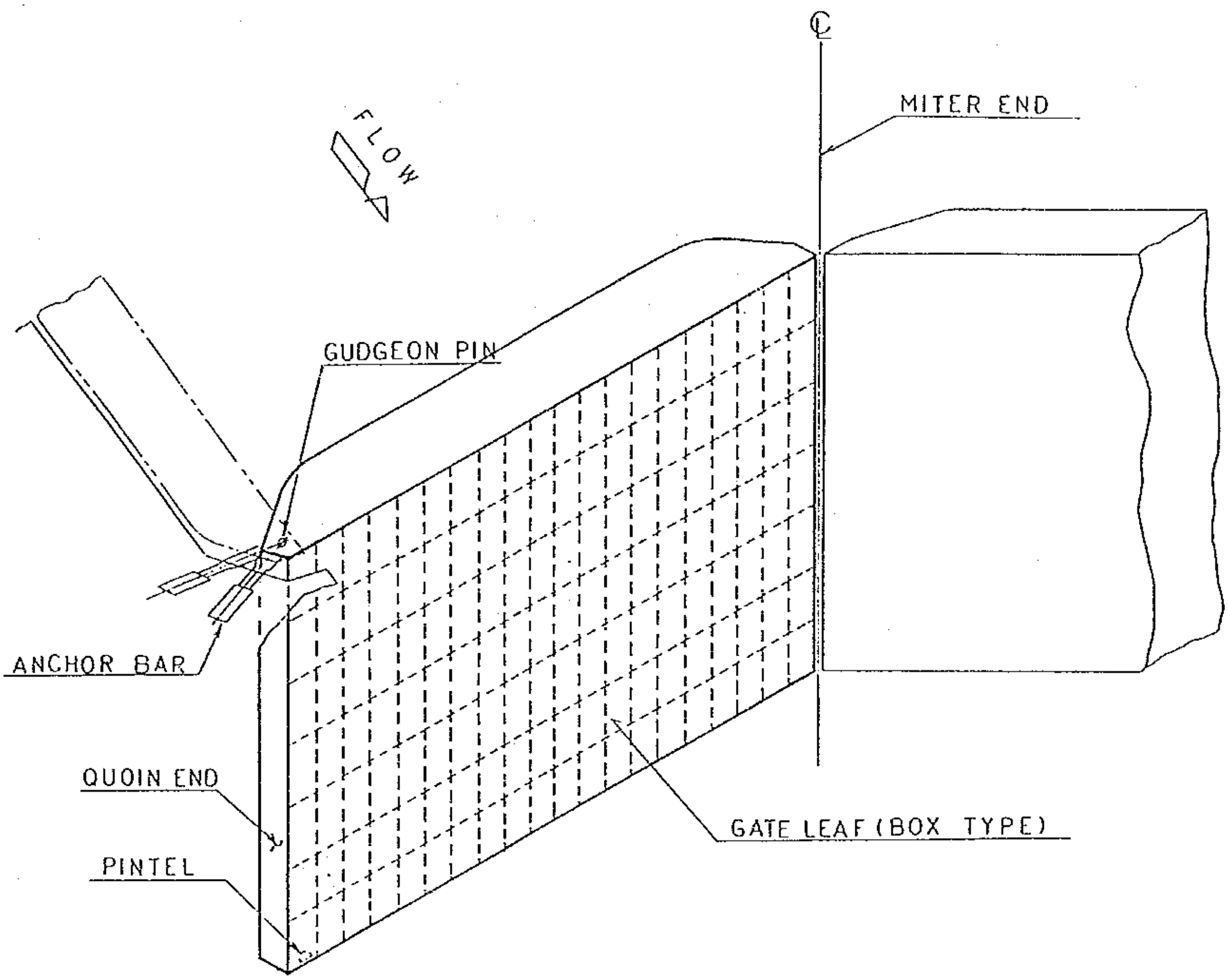


Fig. 4.2.9 General View of Lock Gate

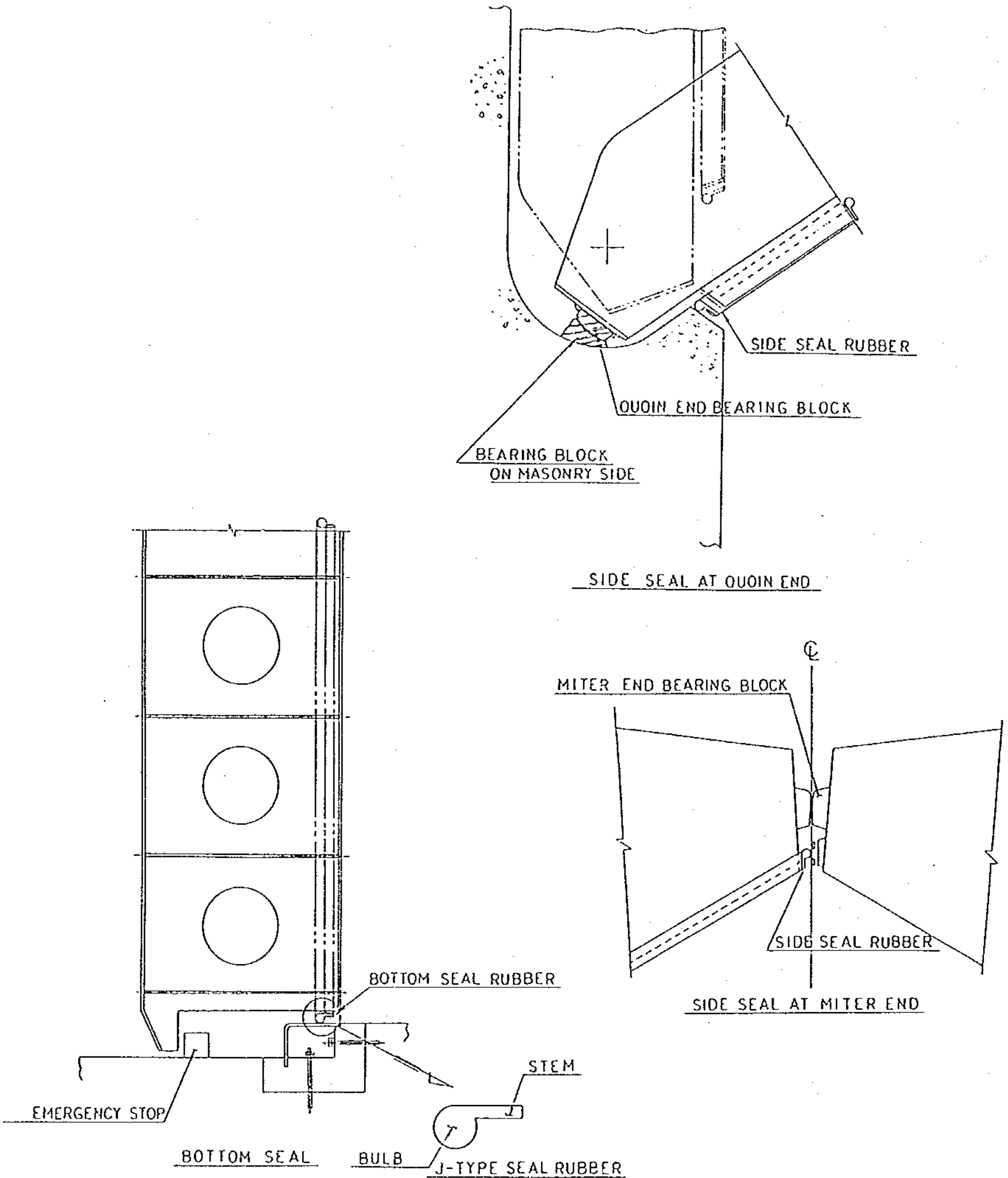


Fig. 4.2.10 Sealing and Bearing Blocks of Lock Gate

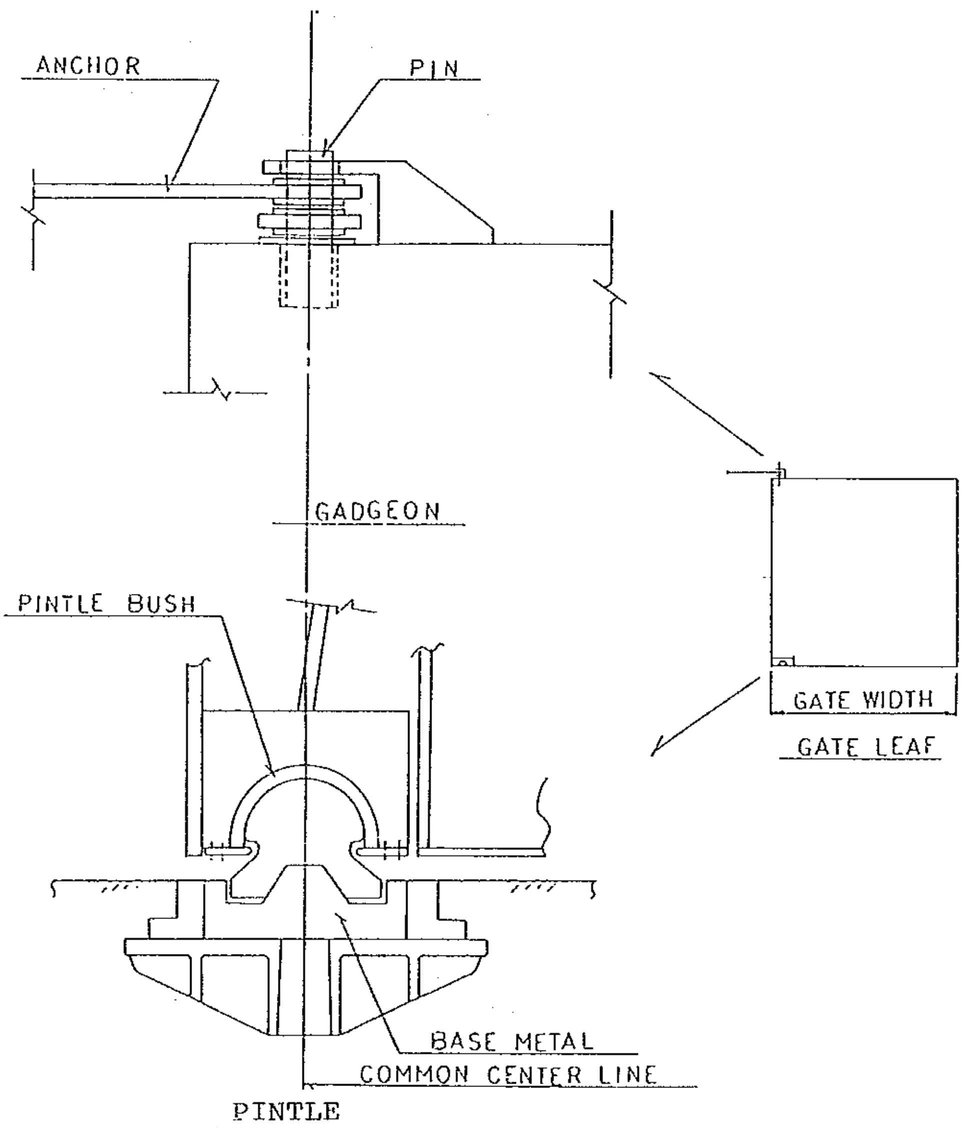


Fig. 4.2.11 Pintle and Gudgeon Pin

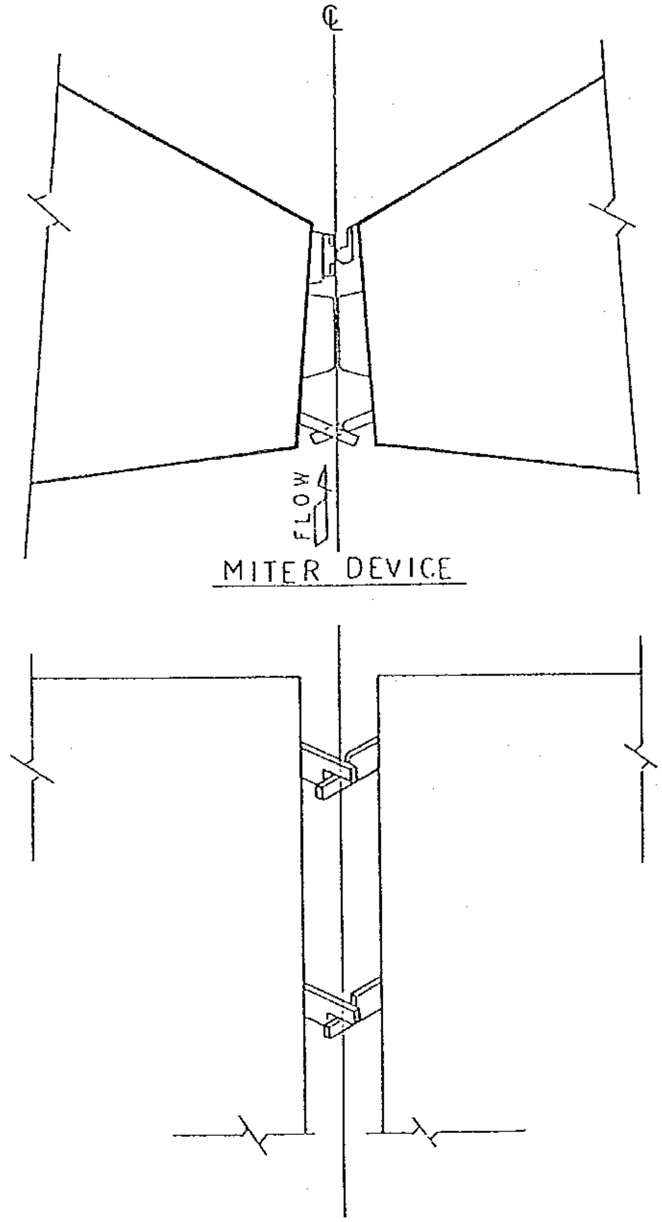


Fig. 4.2.12 Miter Device

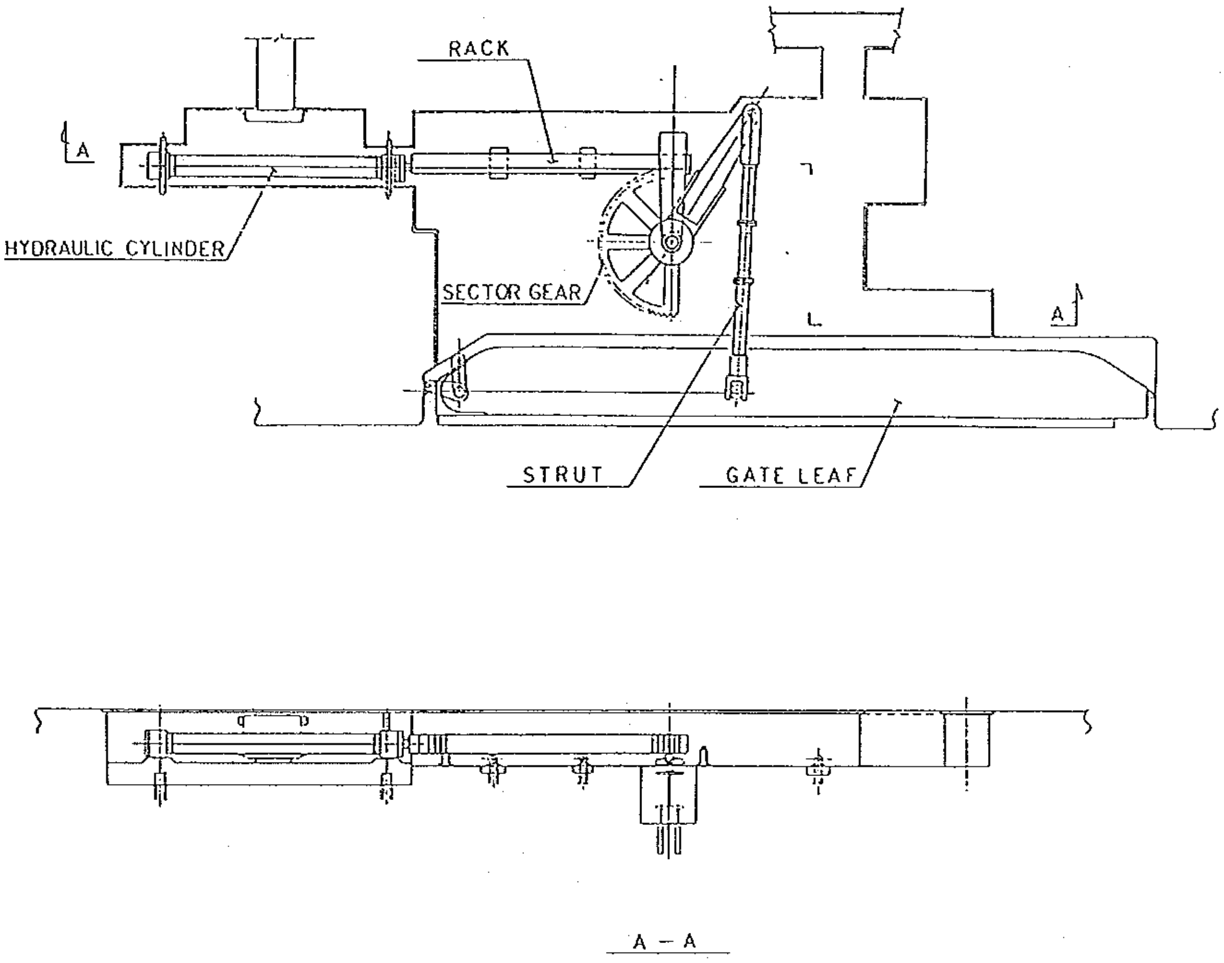


Fig. 4.2.13 General View of Drive Mechanism for Lock Gate

(2) Culvert Gates

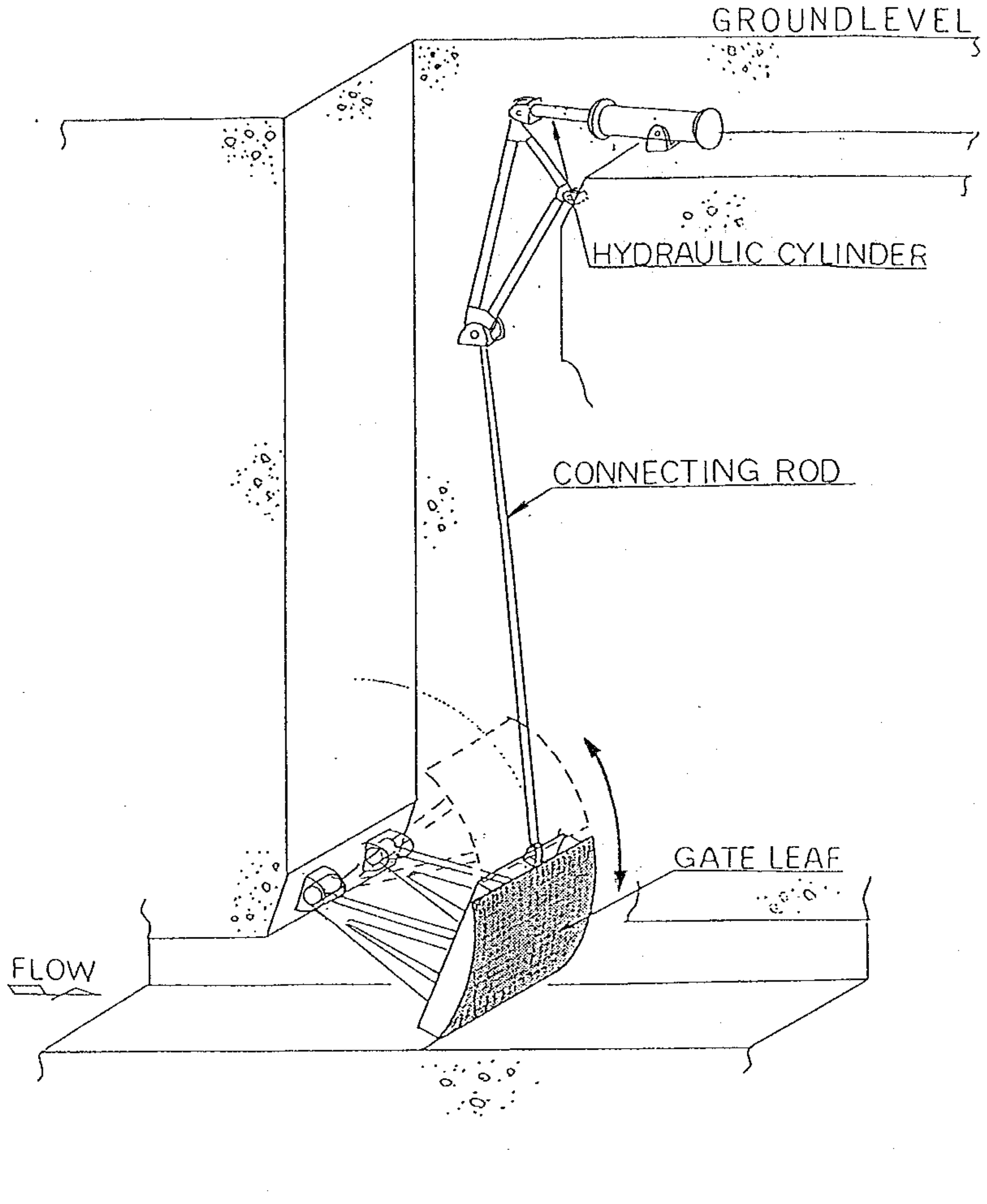


Fig. 4.2.14 General View of Culvert Gate

(3) Emergency Gates

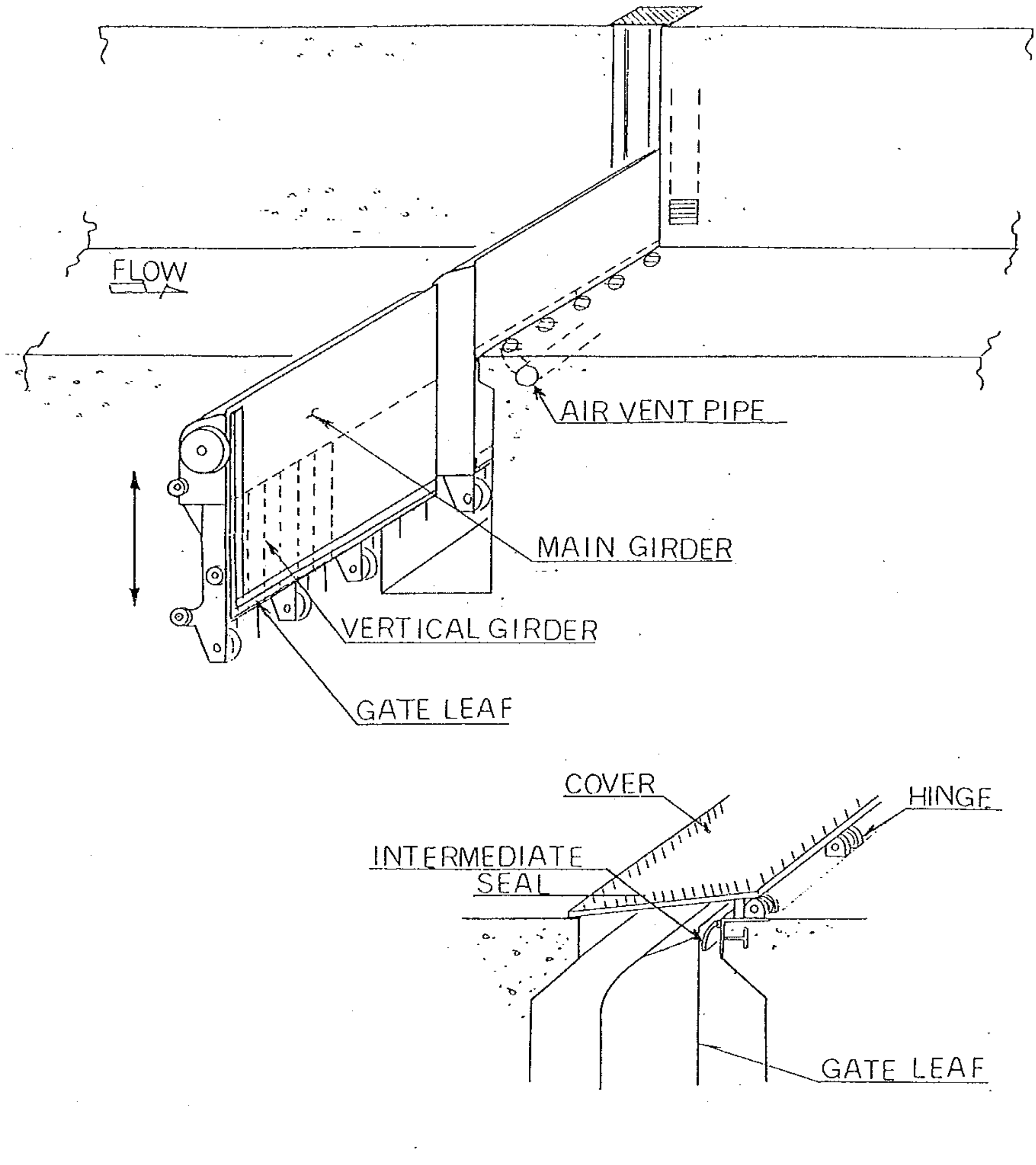


Fig. 4.2.15 General View of Emergency Gate

(4) Maintenance Gates

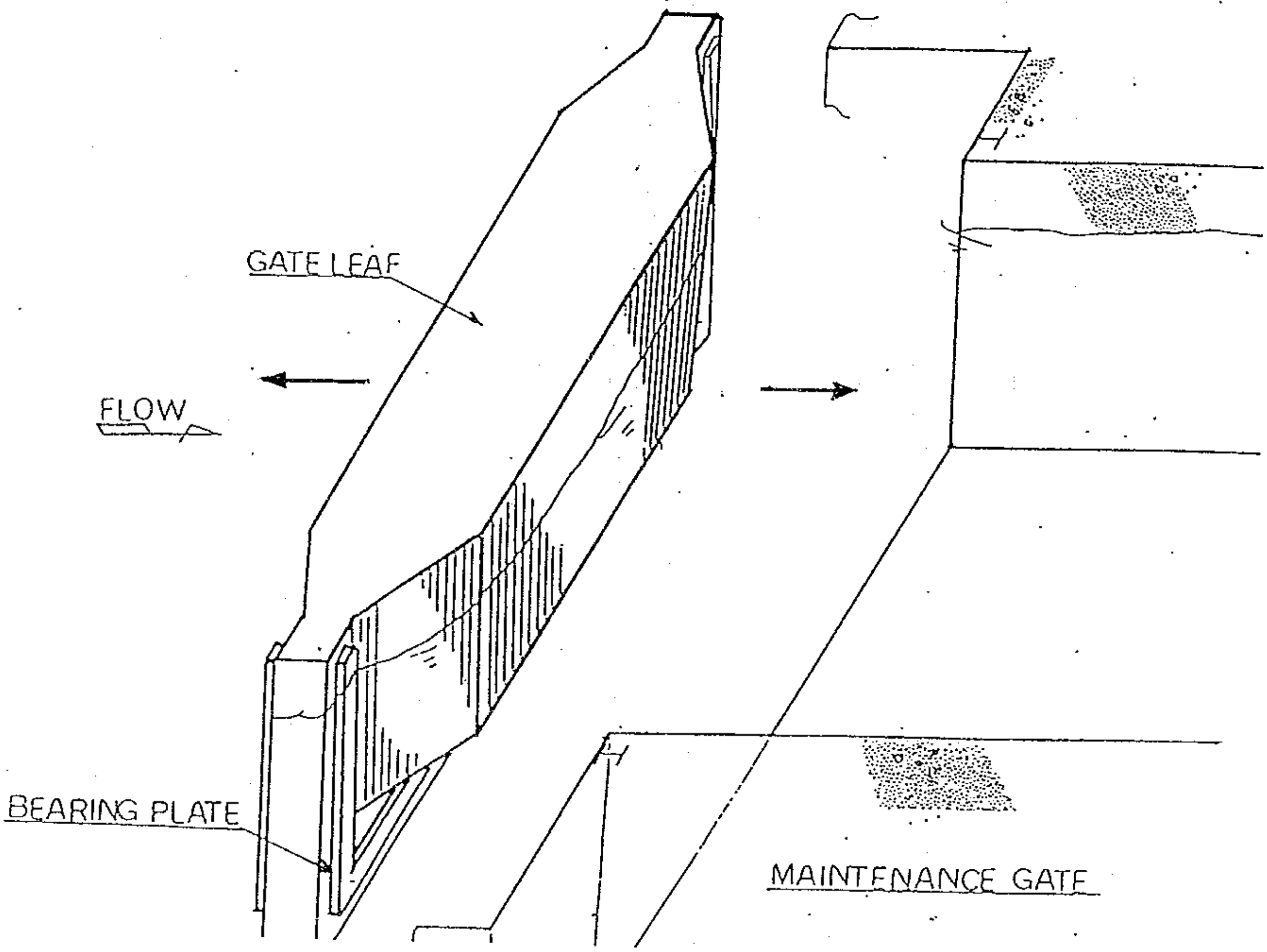


Fig. 4.2.16 General View of Maintenance Gate

4.3 Tidal Gate Structure

4.3.1 General

The sea level canal system will consist of a uniform canal section with single or dual lanes, or a combination of the two with two-way approaches to a central one-way section, according to the study cases (Refer Table 1.4.2).

Since the capacity of a canal allowing one-way operation only is severely constrained by the need for one convoy to completely clear the one-way section before the convoy from the opposite direction can enter, the provision of dual lanes throughout has also been considered. Tidal gates could still be used to control flow between the oceans but the time interval between successive convoys would be significantly reduced. Convoys would pass each other in the central dual lane section while the closed tidal gates prevent flow between the oceans. Then, at the proper time in the tide cycle when only minor differences in elevation exist between the oceans, the gates would shift laterally to the adjacent passing lanes to permit the convoys to complete their transit.

4.3.2 Tidal Gate Operation

Tidal gates would be provided at either end of a relatively long reach of one way or two way canal and they would be used during times when currents would exceed acceptable values. The tidal gate would be opened or closed about every 6 or 12 hours when water levels are approximately equalized throughout the canal, always leaving one gate open and the other closed. Ships would leave and enter the reach between gates from one direction during the period that the gate at that end is open. Conceptual canal operation systems are illustrated in the following Figs. 4.3.1 and 4.3.2.

4.3.3 Tidal Gate Structures

Two tidal gate structures have been proposed, at distances of approximately 25% of the canal total length from the Pacific and Atlantic Oceans.

The gate structures include a hanger shelter, abutments, and a center pier with the main mechanical drive house in the case of the two lane canal.

For the one lane canal, the main mechanical drive house is located on an abutment. The hanger shelter and the abutments and center pier are connected by a concrete basement with rail tracks. The construction works of these facilities would be conducted in dry conditions, so there are no special problems. There would be some difficulties in maintenance works on the rail tracks due to siltation which would disturb smooth operation of the gate. Therefore specially designed cleaning equipment based on a pump dredging system would be necessary.

4.3.4 Canal partition wall

In the two lane Sea Level canal study cases; such as S-2, S-4, S-6, S-8, S-10 and S-12, a partition wall about 26 km long between the lanes is planned in order to keep a different water level resulted in tidal gates operation.

The wall is designed by built-in steel pipe piles with a concrete cap and each pile is connected with interlocking steel joints.

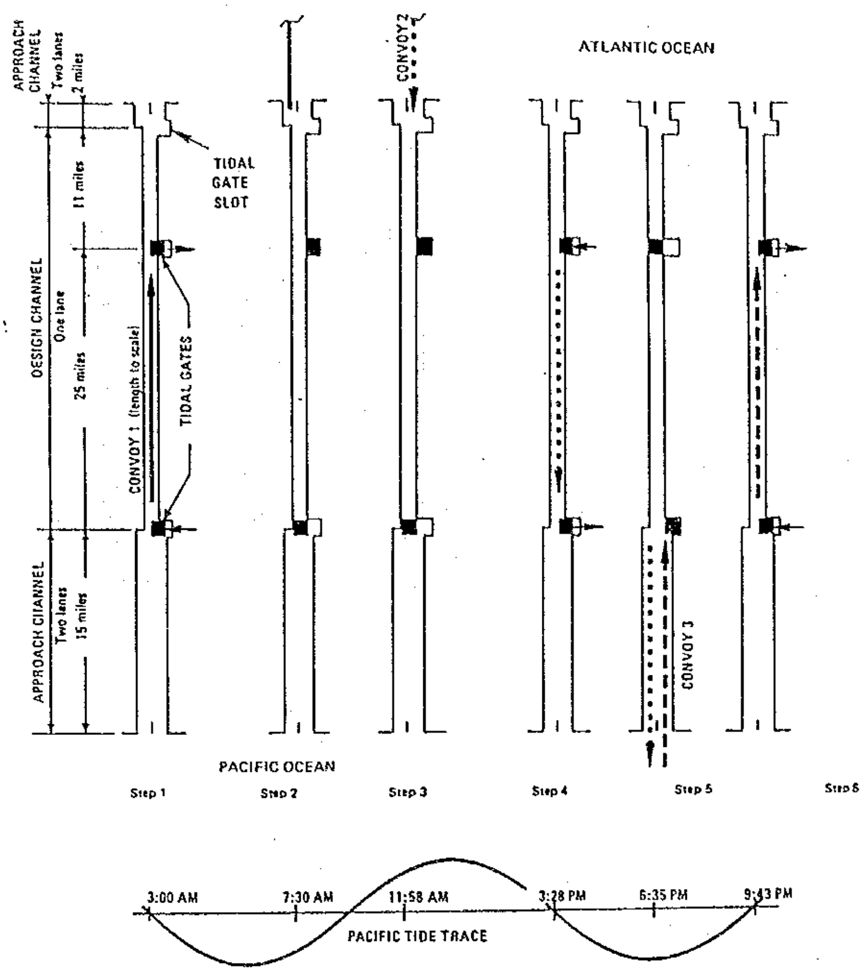


Fig. 4.3.1 Single Lane - Plan of Operation
(Source: IOCS Study)

Step 1. (At 3:00 am) Gates move at mean tide as convey 1 is between them and moving toward the Atlantic.

Step 2. (At 7:30 am) Convoy 1 clears one-way channel.

Step 3. (At 11:58 am) Convoy 2 is about to enter one-way channel from the Atlantic.

Step 4. (At 3:28 pm) Gates move at mean tide as convoy 2 is between them and moving toward the Pacific.

Step 5. (At 6:35 pm) Convoy 2 clears one-way channel as convoy 3 starts to enter it.

Step 6. (At 9:43 pm) Gates move at mean tide as convoy 3 is between them and moving toward the Atlantic.

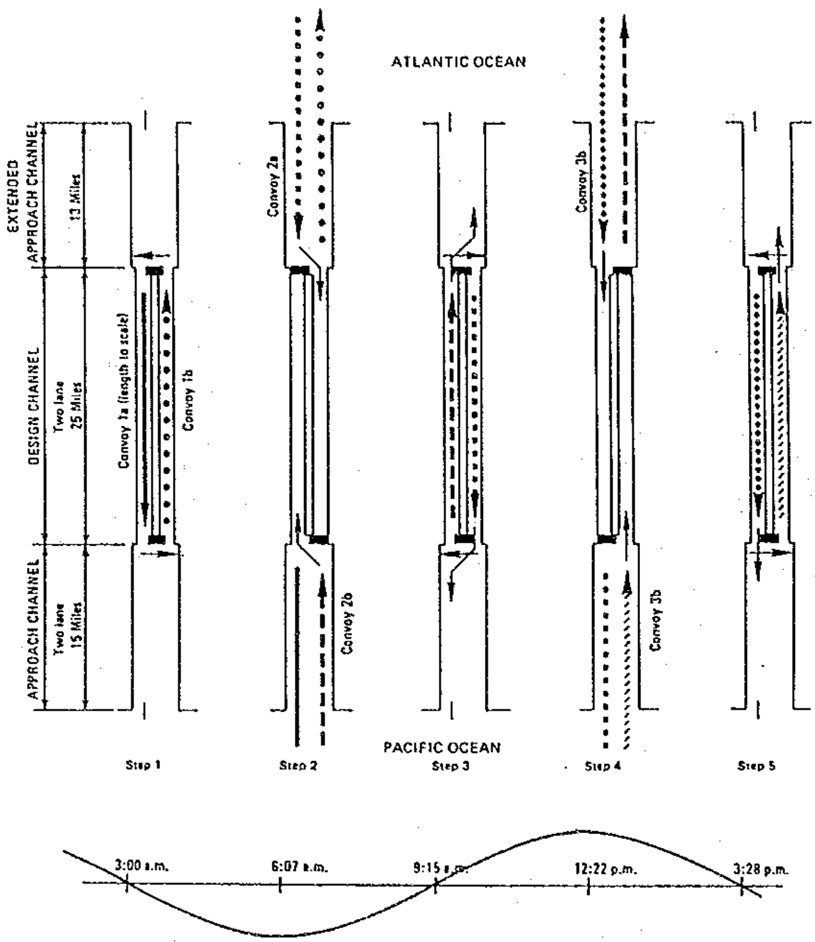


Fig. 4.3.2 Dual Lane - Plan of Operation
(Source: IOCS Study)

Step 1. (At 3:00 am) Gates move at mean tide as convey 1a and 1b are between them and moving toward the approaches.

Step 2. (At 6:07 am) Convoys 1a and 1b have cleared gated reach, and convoys 2a and 2b are about to enter.

Step 3. (At 9:15 am) Gates move at mean tide as convoys 2a and 2b are between them and moving toward the approaches.

Step 4. (At 12:22 pm) Convoys 2a and 2b have cleared gated reach, and convoys 3a and 3b are about to enter.

Step 5. (At 3:28 pm) Gates move at mean tide as convoys 3a and 3b are between them and moving toward the approaches.

4.4 Tidal Gate

4.4.1 General Information

(1) Hydraulic Conditions for Gate Design

Table 4.4.1 shows hydraulic conditions adopted for the Tidal Gate design for Pre-screening. The water elevation on the sea side in the table conforms to the general hydraulic conditions given in 4.2.1 and the water elevation at the tidal gates with those given on Table 2 in the IOCS Memorandum JAX 67. These values correspond to a canal with a closed end 24 miles in length.

In addition to the hydraulic conditions shown in the table, 0.9 m (=3') water head difference is considered for the gate leaf removing a lane to the opposite lane.

Table 4.4.1 Tidal Gate Hydraulic Condition

Water Elevation at Sea Side				Water Elevation at Tidal Gate					
Pacific Coast		Atlantic Coast		Pacific Side		Atlantic Side		Difference	
Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	P->A	A->P
3.3	-2.7	0.5	-0.3	3.96	-3.81	0.61	-0.61	4.57	4.42

(2) Structural Materials and their Allowable Stresses

Material: As proposed at (3)-a) of 4.2.1.
Allowable stress: Allowable stress level corresponding to the failure mode "Yielding" as shown in Table 4.2.3.

(3) Weight Estimation Procedure

As explained in (4) of 4.2.1.

(4) Fabrication

As explained in (5) of 4.2.1.

(5) Transportation

As explained in (6) of 4.2.1.

(6) Installation

As explained in (7) of 4.2.1.

4.4.2 Results of Conceptual Design

(1) Gate Type and Structural System

On Table 4.6.2, various gate types are compared with respect to important technical or economical elements established for the Tidal gate. Although the best evaluation result was given to gate type No. 11 (torsion type rolling gate), the gate type proposed here is a triangular leaf rolling gate because this type was adopted for Zandvliet lock before 1965 and has been in service since the lock was completed. A rubber type gate was also included in the table for the comparisons but was eliminated because of the lower evaluation results. A fatal defect of the rubber type at this time is a lack of removal and reset ability in the wet condition.*

Note*:
This was a concluded after studies of materials supplied by Bridgestone Corporation.

Fig. 4.4.1 shows a general view of the proposed Tidal Gate. The proposal is exactly the same as the IOCS proposal for Route 10 and Route 14S except for the following points.

a) Nominal leaf length conforms to the lane width instead of the canal top width as adopted in IOCS Memorandum JAX 67.
b) Wheel mounting: Preference is given to the combination of vertical and horizontal wheels or rimmed wheels instead of wheels mounted at right angles to the leaf frames as adopted in IOCS Memorandum JAX 67.

c) Water balancing apparatus is provided.

The wheel mounting in b) above is necessary for travel of the gate leaf with 3 feet difference in water head between each side of the leaf. The rollers at the bottom of the leaf will slip off from the rails without this consideration.

The water valancing apparatus in c) above is necessary for the leaf to withstand water loads from both directions. Without this apparatus it is possible that the leaf could topple under water loads from one of the directions.

(2) Numerical Results of Conceptual Design

Table 4.4.2 shows the results of the Tidal Gate sizing.

Table 4.4.2 Design Results for Tidal Gates

Case	Gate	Gate	D.Head 1		D.Head 2		Estimated Weight in Ton			
	Width	H.	PACI	ATLA	PACI	ATLA	LEAF	GFRM	MACH	TOTAL
S-1	147.0	27.0	26.4	23.0	18.6	21.8	6,832	1,025	683	8,540
S-2	147.0	27.0	26.4	23.0	18.6	21.8	6,832	1,025	683	8,540
S-3	171.0	30.0	29.7	26.3	21.9	25.1	9,523	1,428	952	11,903
S-4	171.0	30.0	29.7	26.3	21.9	25.1	9,523	1,428	952	11,903
S-5	183.0	31.4	30.8	27.4	23.0	26.2	10,781	1,617	1,078	13,476
S-6	183.0	31.4	30.8	27.4	23.0	26.2	10,781	1,617	1,078	13,476
S-7	147.0	27.0	26.4	23.0	18.6	21.8	6,832	1,025	683	8,540
S-8	147.0	27.0	26.4	23.0	18.6	21.8	6,832	1,025	683	8,540
S-9	171.0	30.3	29.7	26.3	21.9	25.1	9,523	1,428	952	11,903
S-10	171.0	30.3	29.7	26.3	21.9	25.1	9,523	1,428	952	11,903
S-11	183.0	31.4	30.8	27.4	23.0	26.2	10,781	1,617	1,078	13,476
S-12	183.0	31.4	30.8	27.4	23.0	26.2	10,781	1,617	1,078	13,476
S-13	147.0	27.0	26.4	23.0	18.6	21.8	6,832	1,025	683	8,540
S-14	171.0	30.3	29.7	26.3	21.9	25.1	9,523	1,428	952	11,903
S-15	183.0	31.4	30.8	27.4	23.0	26.2	10,781	1,617	1,078	13,476
S-16	147.0	27.0	26.4	23.0	18.6	21.8	6,832	1,025	683	8,540
S-17	171.0	30.3	29.7	26.3	21.9	25.1	9,523	1,428	952	11,903
S-18	183.0	31.4	30.8	27.4	23.0	26.2	10,781	1,617	1,078	13,476

(3) Sealing

The sides and bottoms of the gate leaf are sealed by J type rubber seals. The sealing has to be done on both Pacific and Atlantic sides. A perfect seal is not necessary but an allowable amount of water leakage relates to capacities of the water balancing apparatus proposed in (1) in the preceding page.

(4) Wheels

Wheels withstand horizontal thrusts while the gates are being removed.

(5) Water Level Balance Apparatus

The water level balance apparatus always keeps the water level in the gate body at the water level on the lowest side (Pacific side or Atlantic side).

(6) Float Tanks

Float tanks of sufficient volume are arranged in the leaf so that the leaf can be removed for maintenance after it is floated by the buoyancy forces of these float tanks. The water in the tanks is drained by pumps installed in the leaf.

(7) Corrosion Protection

An electric corrosion protection system is proposed to reduce corrosion progression in not only embedded parts but also in the gate leaf itself.

(8) Drive Mechanism

Fig. 4.4.1 shows the concept of a rack-pinion type drive mechanism which is the same idea proposed in the Anderson Report for Route 10 and Route 14S.

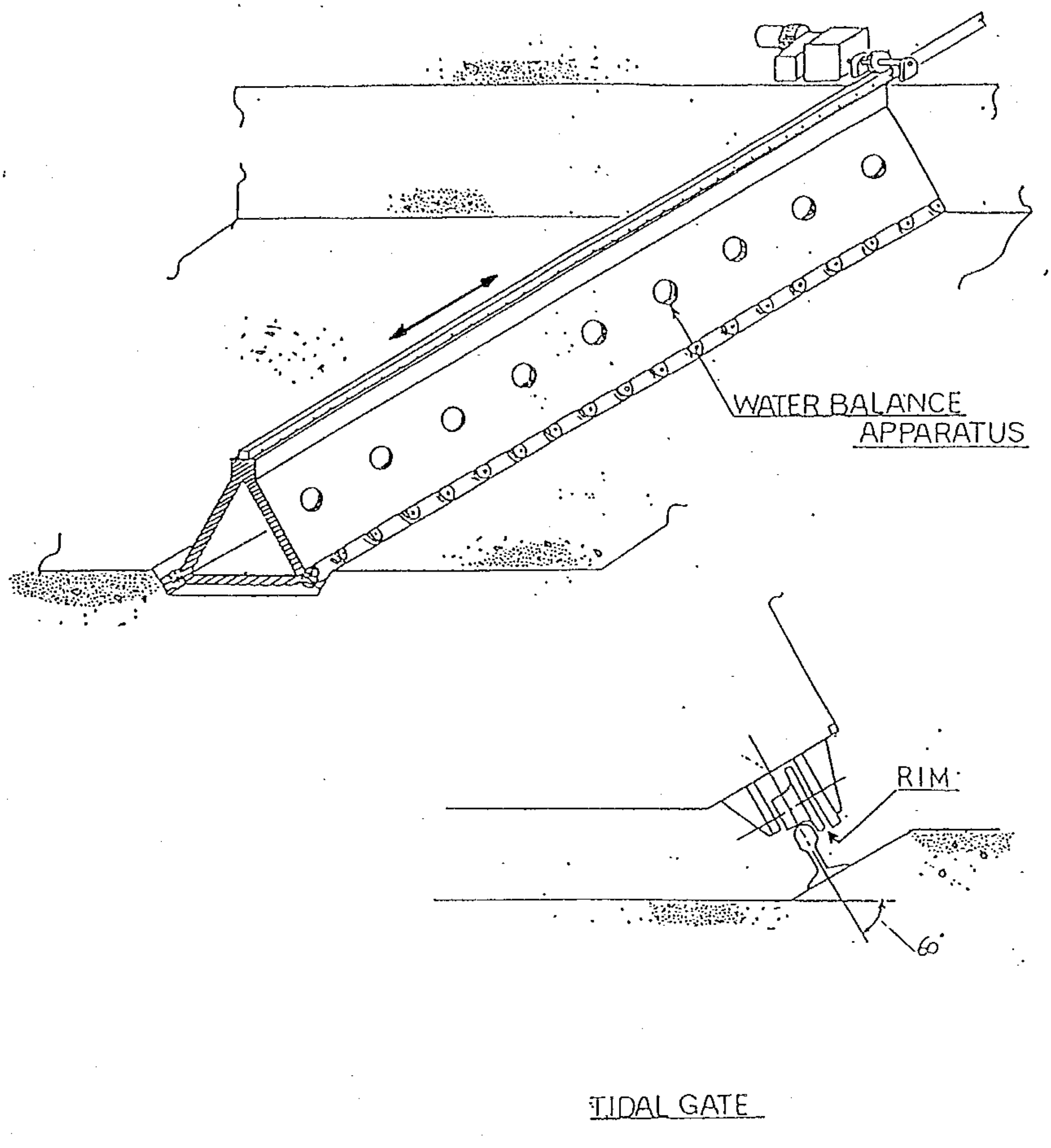


Fig. 4.4.1 General View and Drive Mechanism of the Tidal Gate

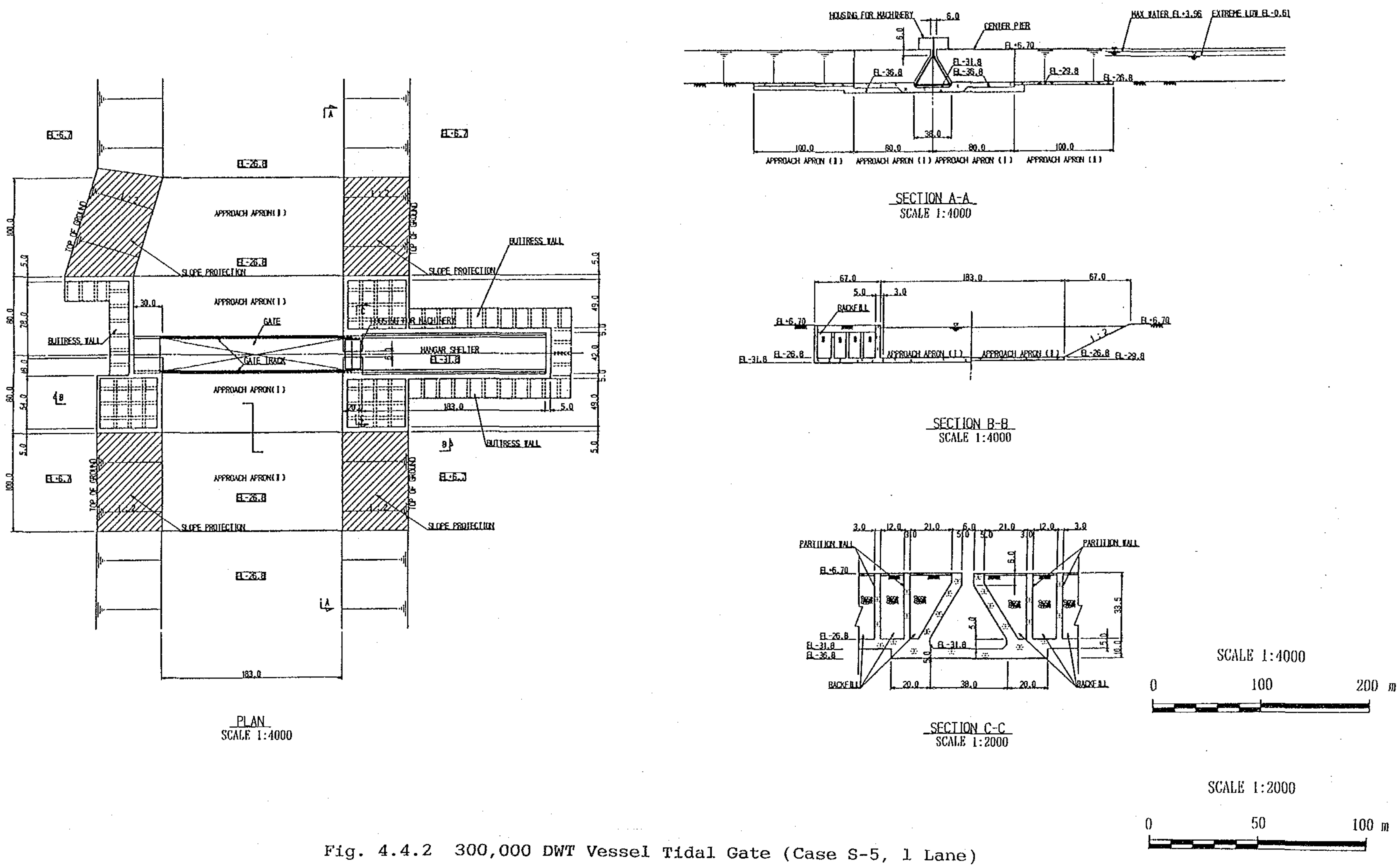
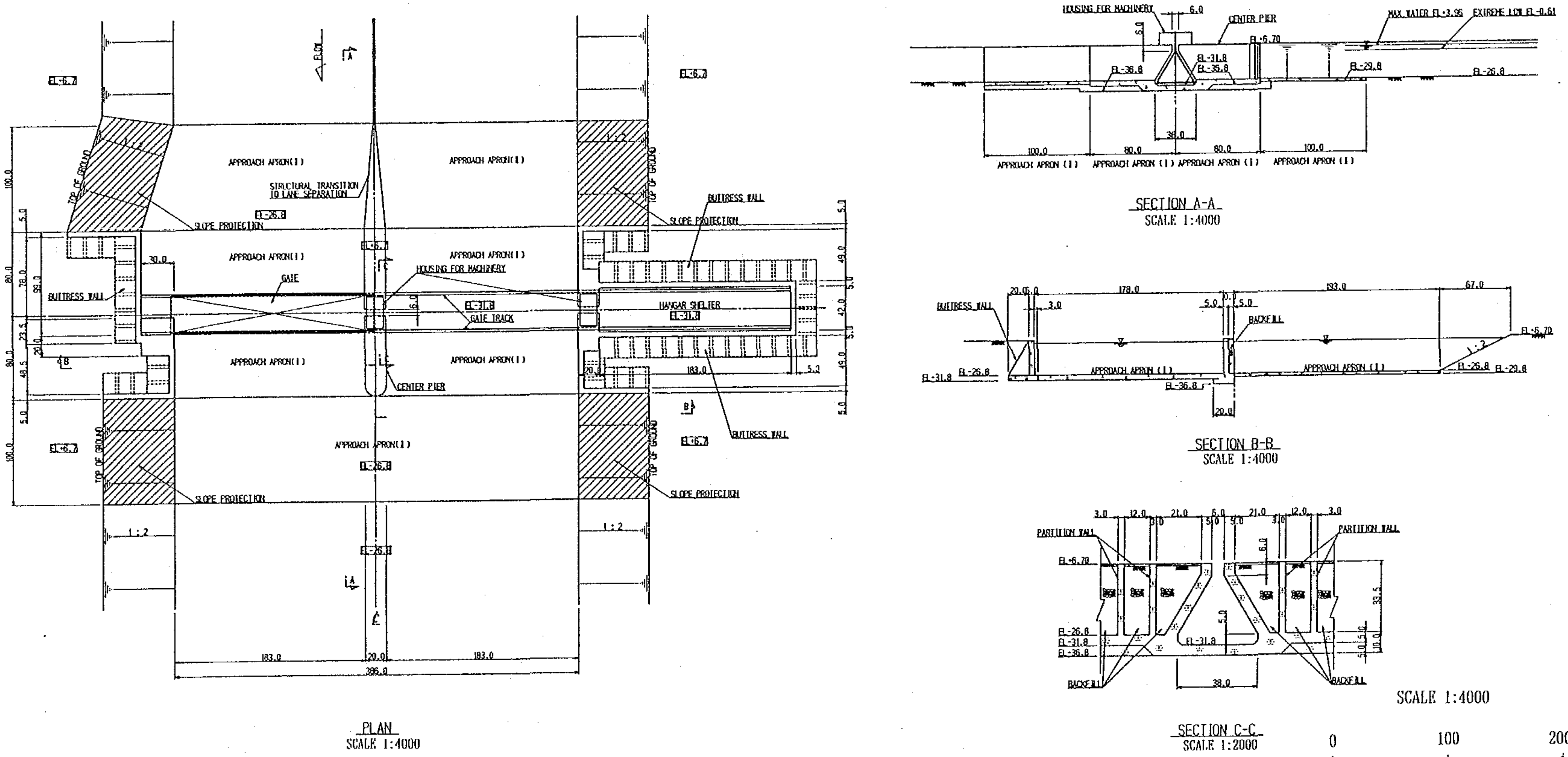


Fig. 4.4.2 300,000 DWT Vessel Tidal Gate (Case S-5, 1 Lane)



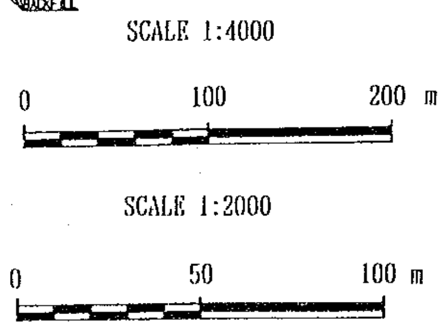


Fig. 4.4.3 300,000 DWT Vessel Tidal Gate (Case S-6, 2 Lanes)

4.5 Mules

4.5.1 Number of Mules and Functional Requirements

Ships are guided and toward through the existing locks by locomotives, known as mules, which run on rails on both sides of the locks and use rack and pinion drive to augment wheel to rail friction. The system works well and is preferred for the new lock systems under consideration. The considerable increase in size of ships for which the new locks are to cater requires the stowage system to be reviewed, not only to allow for the larger forces which will be needed to control the larger ships but also to reduce ship transit times through the new locks as much as possible.

Table 4.5.1 shows mule type and required numbers of mules for each study case. One team for a standard ship consists of 6 mules and one lock provides two teams for 1 lift and three teams for 2 lifts including one team on the return trip.

Table 4.5.2 shows functional requirements for the mule types on Table 4.5.1.

The number of mules in a standard team, the team formation and the functional requirements for the mules were determined based upon experience in handling VLCCs and ULCCs for dockings and wharfing and the following conditions were considered.

(1) Ship propulsion is available at starting, accelerating and stopping to relieve the strain on the locomotives and to minimize lockage time.

The usage of transit ship propulsion as auxiliary means of ship accelerations during lockages has had a long history since the existing Panama canal was constructed and it can be said that the usage is common practice in locking operations there today. For reference purposes, listed below are documents in which there are statements concerning the usage of ship propulsion during lockages.

a) The Panama Canal, Transaction of International Engineering Congress 1915.

b) The Panama Canal Pilot, Panama Canal Commission Maritime Training.

c) Pilot Hand Book, Panama Canal Commission, 1988.

(2) Maximum wind velocity is 13 m/sec.

(3) The maximum angle of tow lines with respect to the horizontal is 55 degrees which was derived in the Third Lock Plan study for a one lift lock of 200' width x 1500' length.

(4) Number of mules assigned is 4, 6 or 8 depending on ship size. These numbers are equal to those shown in c) of (1) above.

Table 4.5.1 Mule Arrangements

Case	DWT	Lock L	Lock W	Rise	Lift	Mule Type	Rq. Num.
L-1	100,000	360	47	90	2	M1	36
L-2	100,000	360	47	85	2	M1	36
L-2'	100,000	360	47	85	1	M1	24
L-3	100,000	360	47	55	1	M1	24
L-4	150,000	410	54	90	2	M2	36
L-5	150,000	410	54	85	2	M2	36
L-6	150,000	410	54	55	1	M2	24
L-7	250,000	485	63	90	2	M2	36
L-8	250,000	485	63	85	2	M2	36
L-9	250,000	485	63	55	1	M2	24
L-10	100,000	360	47	85	2	M1	36
L-11	100,000	360	47	55	1	M1	24
L-12	100,000	360	47	30	1	M1	24
L-13	150,000	410	54	85	2	M2	36
L-14	150,000	410	54	55	1	M2	24
L-15	150,000	410	54	30	1	M2	24
L-16	250,000	485	63	90	2	M2	36
L-17	250,000	485	63	85	1	M2	24
L-18	250,000	485	63	30	1	M2	24

Table 4.5.2 Functional Requirements for Mules

No.	Function	Examples of Detail Function
M1	Equal to the latest specification of the mules now in Service.	Pulling force (Max): 35,000 lbs per on cable (16 ton) Number of cables: 2 Speed: 1, 2, 3, 6 and 9 M.P.H. Cable length: Max. 500' (150 m) Weight: 55 short ton
M2	Twice the pulling capacity of M1	Pulling force (Max): 32 ton per on cable Number of cables: 2 Speed: 0.5, 1, 2, 3, 6 and 9 M.P.H. Cable length: Max. 300 m

4.5.2 Specifications

		M1	M2
(1)	Dimension(m):	L10.4xW3.0xH3.8	L15xW3.3xH4.5
(2)	Weight(ton):	50	88 (approx.)
(3)	Drive Motor:	2 units	2 units
(4)	Drive Motor Size:	170HPx60Hzx440V	300HPx60Hzx440V
(5)	Cable Size(inch):	1	1-1/4
(6)	Rail Gauge(mm):	1,524	1,676

4.5.3 Electric Power Source

The electric power source is A.C. The advantages of A.C. compared to D.C. supporting this selection were the low cost of motors, low cost of transformers etc.

4.6 Technical Feasibility

4.6.1 Lock Gate

(1) General

Although the Lower Lock Gate L-2' is the largest with a height of 48.4m, it is still feasible. This is because the lock width is comparatively small (47m).

The heaviest unit weight is 2.74 ton/m2 for the Middle Gate in study case L-12 (LxH=63x38.5), whereas the heaviest leaf weight is 3,384 ton for the Lower Gate in study case L-13 (LxH=63x44.4).

(2) Optimization of Gate Design

Although possible leaf weights were derived for the all study cases, optimization of the design of each gate is left for further study in Phase II. The following are examples of design factors which may be effective in decreasing costs or in improving function.

a) Gate Depth

In the preliminary design of the three model cases, ratios of lock widths over gate depths (thicknesses) are 15.2 for the smaller two models and 8.8 for the largest model. Although the ratio 15.2 is approximately equal to the ratio for the existing Panama locks (SQ) and was selected as a result of studies for weight optimization, the real optimum value may be another ratio. The ratio 8.8 was the highest necessary value to keep a plate thickness limitation for gate leaves. This value may require comparatively large gate depths which may result in increasing costs for masonry work since a large storage recess for the gate would be required. Optimization of gate and masonry work costs together may be necessary in this case.

b) Increasing the Fatigue Strength

The followings are examples of ideas by which joint strengths are improved and eventually considerable cost reductions may be realized.

a. To decrease stress levels of welded joints in critical areas.

b. To eliminate such welded joints which would be classified as having low grades of fatigue strength.

c. To apply high tension bolt joints wherever possible instead of welded joints.

c) A proper combination of structural steels of various strength levels.

A proper combination of various strength materials decreases leaf weights and eventually total costs may be reduced notwithstanding the increase in costs per unit weight.

In the studies of design optimization including the above mentioned factors, it is predicted that the two restrictions below may emerge as major obstacles to be overcome.

a. Allowable stress levels for fatigue designs.

b. Maximum thickness restrictions of welded joints.

Overcoming the above would require intensive design investigations but such investigations should be worth while in this case because the capital expenditure to complete the whole project is large and there are significant benefits to be gained. Nevertheless, it is very important that the possibility of improvements has to be strictly evaluated before starting any experiments.

(3) Alternative Proposal for Lock Gate

On Table 4.6.1, various gate types are compared with respect to important technical or economical elements established for Lock Gate. Although the best evaluation result was given to No. 11 (torsion type rolling gate), it was not recommended in our proposal at (1) of 4.2.2 only because of lack of actual installations records. Since torsion type flap gates (No. 4 on the same Table) do have a proven record in usage and their dimensions are indicative of torsion type rolling Lock Gates being feasible, this type can be considered as an alternative to the Miter gates.

Fig. 4.6.1 shows the Alternative for the Lock Gate.

This gate withstands rotational moment with its torsional rigidity and both gate ends are rigidly supported against the whole torsional moment whose magnitude is controlled by pair forces of hydraulic pressure acting on the gate leaf and reaction forces acting along the gate bottom. For this reason, this gate can be called a torsion type rolling gate.

Advantages of this gates are as followings:

a) Leaf weight is remarkably smaller than a bending type gate (the Miter type) because of the superiority of torsional rigidity to bending rigidity. Extent of the weight reductions may in some cases be more than 50%.

b) Very advantageous for fatigue designs due to lower tensile stresses. A magnitude of tensile stresses in this type of structures is equal to that of a shearing stress whose allowable stress is usually $1/\sqrt{3}$ of the allowable stress for tensile stress in bending type structures.

c) Very advantageous for fabrication because of the reduced thicknesses of shell plates comprising the gate leaves. Maximum plate thickness of the major portions of gate leaves in case of bending type Lock Gates will be up to 100mm whereas that of torsion types 20 - 40 mm.

d) Very stable for un-balanced water pressure such as the pressure of ship propulsion blows just in front of the Lock Gates.

Another possible alternative is the torsional type slide gate the leaf of which would be the lowest in cost and which has almost no mechanical parts. The reason why it was not recommended was mainly the leaf's gravity height change during operations that was likely to result in expensive hoist mechanisms and high operation costs. Nevertheless, this gate type is still difficult to omit completely because the leaf would have the most simple construction.

Table 4.6.1 Comparison of Gate Types for Lock Gates

MOVEMENT	DIRECTION OF MOVEMENT	NO	STRUCTURAL TYPE	FUNCTION		INITIAL COST	MAINTENANCE COST			HOIST LOAD		
				CHAMBER L[2] EFFICIENCY	STAB. AGAINST PROPULSION[3]		SAND & SILT	REMOVAL & RESET	MECHANI-CAL PART	FRICTION	GRAV. EL. CHANGE[4]	HYDR. INERT[5]
ROTATION	VERTICAL	2	RADIAL(DOUBLE)	○	○	◎	○	×	△	○	○	○
		3	MITER	○	△	◎ (shaded)	△	○	○	○	○	△
	HORIZONTAL	4	FLAP(TORTIONAL)	×								
		5	FLAP(BENDING)	×								
		6	RADIAL(SINK TYP)	×								
LINEAR	VERTICAL	9 † 11	SLIDE(DROP)[6] (TORSIONAL)	○	○	◎ (shaded)	△	○	○	△	×	○
	HORIZONTAL	10	TRIANGLE	×								
		11	TORTIONAL	○	○	◎ (shaded)	◎	○	○	△	○	○

NOTE 1. NO; CORRESPONDS TO NO. OF SKETCHES ON FIG 4.6.3

2. CHAMBER L EFFICIENCY; EFFECTIVE CHAMBER LENGTH FOR LOCKAGES OVER ACTUAL CHAMBER LENGHTS. THE EFFECTIVE CHAMBER LENGTH = ACTUAL CHAMBER LENGHT - THE CHAMBER LENGTH WHICH CAN NOT BE USED FOR LOCKAGES BECAUSE OF EXISTANCE OR OPERATION OF A LOCK GATE.

3. STAB. AGAINST PROPULSION; STABILITY OF GATE LEAF SUPPORTS AGAINST SHIP PROPULSION BROWS.

4. GRAV. EL. CHANGE; GRAVITY CENTER ELEVETATION CHANGE OF A GATE LEAF. × MEANS THAT THERE IS THE CHANGE DURING LEAF OPERATIONS.

5. HYDRO. INERT; HYDRAULIC INERTIA FORCE. △ MEANS THAT HYDRAULIC INERTIA FORCE WILL ACTS ON LEAF SKINS DURING LEAF OPERATIONS.

6. SLIDE(DROP) IS A GATE TYPE CORRESPONDING TO NO 9 IN FIG .4.6.2 EXCEPT THAT SLIDE SHOES REPLACE ROLLERS AND GATE LEAF IS TORSIONAL TYPE INSTEAD OF BENDING.

7. EVALUATION MARKS

×;NOT ACCEPTABLE, △;JUST AT ACCEPTABLE LEVEL, ○ACCEPTABLE WITHOUT ANY CONDITIONS,

◎;STRONGLY RECOMENDABLE

8. (shaded) SHOWS RESULTS OF QUANTITATIVE STUDIES

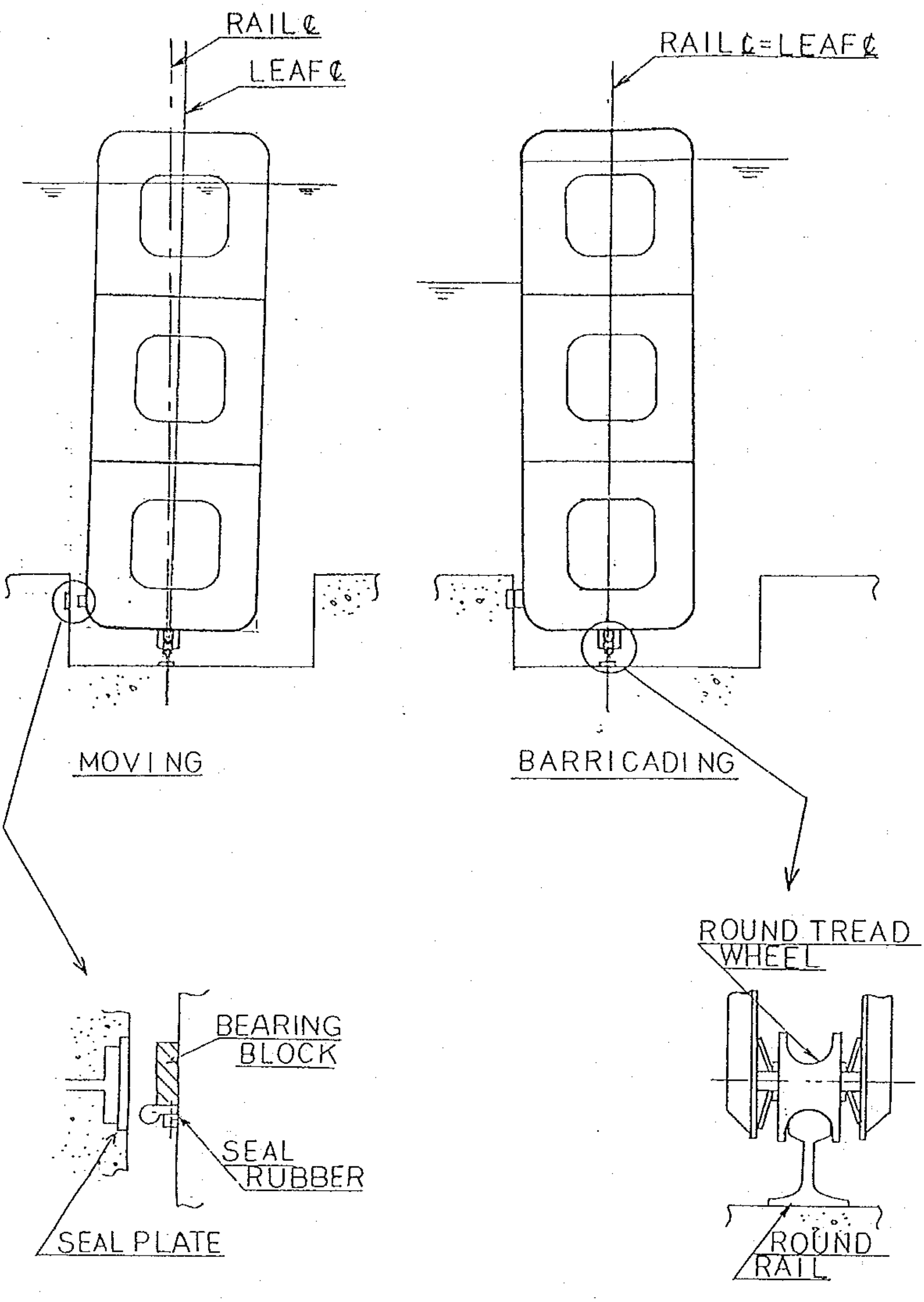


Fig. 4.6.1 Alternative for Lock Gate

4.6.2 Culvert Gate

(1) General

Culvert Gates in all study cases are fundamentally feasible.

(2) Technical items to be studied in Phase 2

a) Emergency closures of Culvert Gates

It is predicted that the water in the Culvert Gate chambers will surge due to emergency closures of the Culvert Gates. The amount of the surging will be checked at the next study phase and the chamber arrangements will be reviewed if necessary. Nevertheless, the feasibility of the Culvert Gates would not be affected.

b) Stability of the flow passing through the Culvert Gate chamber

Since the gate chamber length is comparatively large to accommodate a radial gate and flow velocity in the culvert will be very high in some study cases, hydraulic studies will be necessary, at a later stage of the design, on the stability of the flow passing through the chamber. And in the worst case, reviewing of the gate type selection, including the Fixed Wheel gates, may become necessary. Nevertheless, no big change is likely in the cost of the Culvert gate.

4.6.3 Emergency Gate

(1) General

Emergency Gates in all study cases are fundamentally feasible.

(2) Configuration of the Gate Top

Detail studies including hydraulic model experiments will be necessary to determine hydraulic characteristics of the gate top configurations. This has to be done at a later stage before finalizing the emergency gate design.

(3) Structural Design of the Gate Leaves

The large torsional rigidity of the main box girder may cause difficulties in sealing at the gate bottom corners. Proper distribution of bending rigidities in vertical girders under the main girder will resolve this problem.

(4) Driving Mechanisms

Information is currently lacking with regard to the central jack type hoist machine energized by fire pump pressure. Ordinary hydraulic power cylinders combined with a pulley system would also be applicable for this gate.

4.6.4 Maintenance Gate

(1) General

Maintenance Gates in all study cases are fundamentally feasible.

(2) Structural Design of the Gate Leaves

The large torsional rigidity of the main box girder may cause difficulties in sealing at the gate bottom corners and in controlling bending stresses in vertical girders which are located around mid-ship of the gate leaf. Proper distribution of rigidities between main girders and vertical girders will resolve these problems. The leaf weights estimated may be a little high and reductions should be possible in the next stage of the study. In addition to this, further savings in weight will be possible after considering the following conditions.

a) Adaptation of auxiliary maintenance gates for the upper operating gate.

b) Application of torsional type gates to the maintenance gate design. It is quite possible and remarkable weight reduction could be achieved.

4.6.5 Tidal Gate

(1) General

Tidal Gates in all study cases are fundamentally feasible.

(2) Facilities for Maintenance of Tidal Gate

Facilities for maintenance of Tidal Gates were excluded from the study for the pre-screening. Maintenance facility could includes not only docks for the gate leaves but also some means for carrying out maintenance of embedded parts in dry conditionary.

(3) Alternative Proposal

On Table 4.6.2, various gate types are compared with respect to important technical or economical elements established for the Tidal gate. Although the best evaluation result was given to No. 11 (torsion type rolling gate), it was not recommended in our proposal in (1) of 4.3.2 only because of the lack of existing installations. Since torsion type flap gates (No. 4 on the same Table) have do have a proven record in usage and their dimensions are inductive, this type can be considered as an alternative to the triangular rolling gates.

Fig. 4.6.2 shows the Alternative for the Tidal Gate.

This gate withstands rotational moment with its torsional rigidity and both gate ends are rigidly supported against the whole torsional moment whose magnitude is controlled by pair forces of hydraulic pressure acting on the gate leaf and reaction forces acting along the gate bottom. For this reason, this gate can be called a torsion type rolling gate.

Advantages of this gates are as followings:

a) Leaf weight is much smaller than the Triangular Section Rolling Gate.

b) Ability to withstand pressure on both sides of the leaf without pressure balance apparatus.

c) Reduced maintenance costs.

Table 4.6.2 Comparison of Gate Types for Tidal Gates

MOVEMENT	DIRECTION	NO	STRUCTURAL TYPE	FUNCTION	INITIAL COST	COST OF SAND & SILT REMOVAL	MAINTE. COST	REMOVAL & RESET	HOIST LOAD
ROTATION	VERTICAL	1	RADIAL(SINGLE)	○	△	×	×	×	○
		2	RADIAL(DOUBLE)	○	△	△	×	×	○
		3	MITER	×					
	HORIZONTAL	4	FLAP(TORTIONAL)	○	◎	○	△	○	△
		5	FLAP(BENDING)	○	△	△	○	○	△
		6	RADIAL(SINK TYP)	○	×	◎	◎	×	○
		7	VISOR	×					
LINEAR	VERTICAL	8	ROLLER(HOIST UP)	○	×	○	○	△	×
		9	ROLLER(DROP)	○	△	△	△	△	○
	HORIZONTAL	10	TRIANGLE	○	○	○	△	○	○
		11	TORTIONAL	○	◎	◎	○	○	○
CONFIGU-LATION	INFLATED/ DEFLATED	12	RUBBER DAM	○	△	◎	◎	×	△

NOTE 1. NO; CORRESPONDS TO NO. OF SKETCHES ON FIG. 4.6.3.

2. EVALUATION MARKS

× ; NOT ACCEPTABLE, △ ; JUST AT ACCEPTABLE LEVEL, ○ ACCEPTABLE WITHOUT ANY CONDITIONS,

◎ ; STRONGLY RECOMENDABLE

3. (shaded) SHOWS RESULTS OF QUANTITATIVE STUDIES

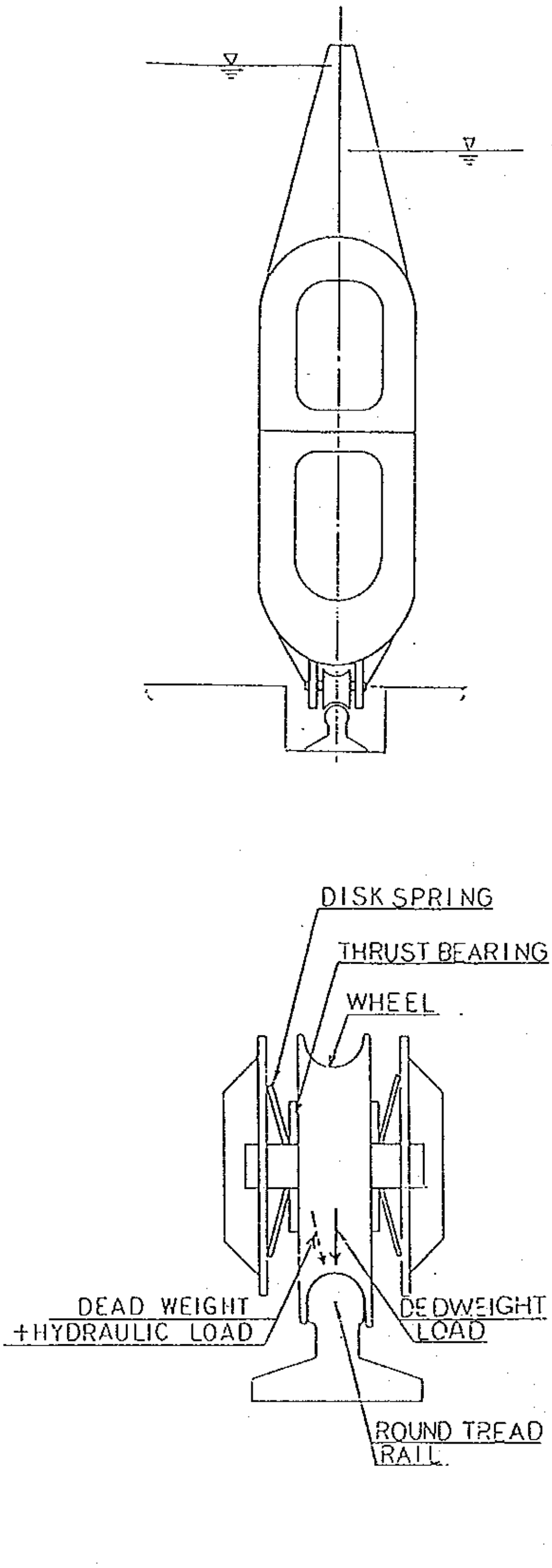


Fig. 4.6.2 Alternative for Tidal Gate

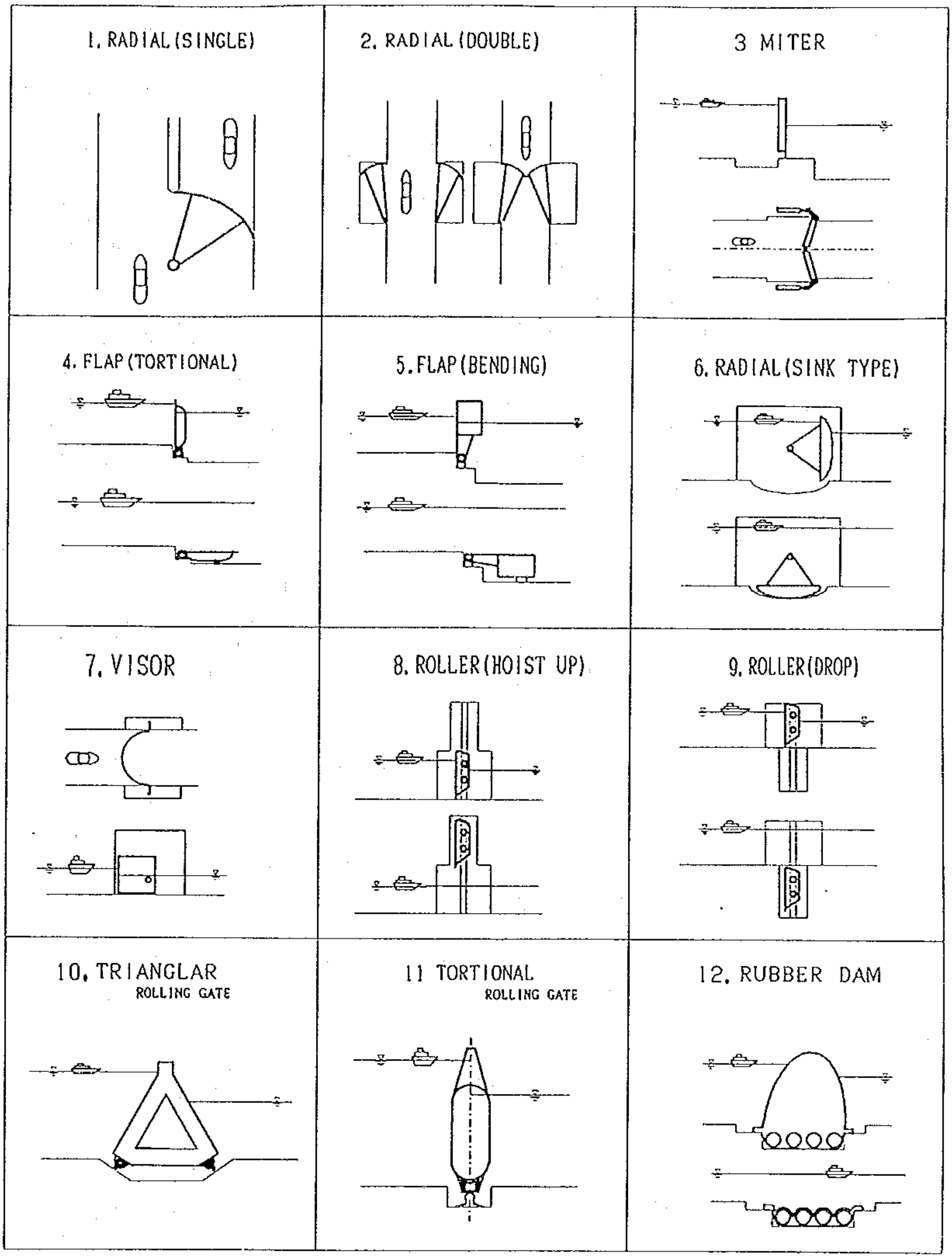


Fig. 4.6.3 Various Gate Types for Lock Gate and Tidal Gates

4.6.6 Mules

(1) General

Mules in all study cases are fundamentally feasible.

(2) Review of Mule Capacity in Phase 2

The capacity of the mule type M2 was tentatively decided to be twice that of the mule type M1 whose specification is exactly equal to the mules now in service at the existing Panama canal. These capacities are only for the Phase 1 study purpose and will be reviewed in the Phase 2 study. It is expected that the proper capacity ratio between M2 and M1 is between 1.0 and 2.0. The following are technical items to be studied in the review work for the next phase.

a) Necessary towing force for the transit ship running at the green light speed of mules (maximum towing speed established for various vessel sizes). In this calculation, the following elements are to be considered as well as wind force.

   a. Friction force on the hull surfaces from the flow due to ship speed plus water speed with respect to the lock. The later element relates to the movements of the transit ship herself.

   b. Friction force on the lock wall of the water flow.

   c. Resistance force corresponding to the absolute velocity head of the water flow along the ship.

b) The maximum stopping distance of the transit ships without ship propulsion aids. This calculation corresponds to an emergency condition and the effects of a) to c). above can be included if their minimum values are found. The number of mules at a braking load is the number of assigned mules for the ship minus 2.

c) Necessity of a hydraulic assistance for lockages. If the answer is yes, then modification of the culvert arrangements would follow.

(3) Alternative Mule Operation System

The followings is an alternative idea for the mule operation system. Specific features of this alternative compared with the proposal are minimum number of mules for a towing team and no aid from ship propulsion.

a) Number of mules for a team: 4

b) Calculated Cable Pulling force per mule.

Ship Size (DWT)	Inertia Force (ton)	Wind Force (ton)	Cable Pulling Force (ton)
100,000	56	15	115
150,000	58	18	124
250,000	95	24	173

The following conditions were considered in the above calculation.

a) Towing speeds:
2mph for ship 150,000 and greater, 3mph for smaller vessels

b) Acceleration:
The maximum towing speeds is reached in a 5 minutes.

c) Wake volume: 10% of the ship displacement

d) Maximum wind velocity is 13 m/sec.

e) Angle of tow lines with respect to the direction of motion in a horizontal plane: 45 degrees

f) The maximum angle of tow lines with respect to the horizontal: 55 degrees

No feasibility study was made on this alternative.

CHAPTER 5 - INCIDENTAL STRUCTURES

5.1 New Dams

New Dams are proposed for the high rise lock canal systems with water levels of 90' and 85' (L-1, L-2, L-2', L-4, L-5, L-7, L-8, L-10, L-13, L-16) in order to increase the supply of water for canal lock operations.

5.1.1 Rivers

Gatun Lake is the reservoir created by the Gatun dam and spillway at the mouth of the Rio Chagres and covers a drainage area of approximately 3,339 km2. Madden Lake is upstream from Gatun Lake and is the reservoir created by the dam across the upper Rio Chagres. It covers an area of approximately 1,018 km2.

Fig. 5.1.1. shows the location of river and proposed new dams.

The main rivers flowing into Madden Lake flow from east to west and consist of the Rio Chagres, Rio Pequeni and Rio Boqueron of which the Rio Chagres drainage area is the largest. The drainage areas of these three rivers account for about 70 percent of the Madden Lake basin. The main rivers flowing into Gatun Lake, aside from the Rio Chagres, are the Rio Gatun from the north-eastern side of the lake and the Rio Trinidad, Rio Ciri Grande and Rio Ciricito from the western side of the lake flowing from south to north.

Adjoining to the Rio Ciricito basin and outside the Gatun Lake basin is the Rio Indio. The Rio Indio has the largest drainage area of these rivers.

5.1.2 New Dams

In order to supply the water used in canal operation, 7 new dam sites have been considered within or nearby the Gatun Lake basin. Some of the dam sites have been nominated as potential sites in previous studies.

The dam sites and the existing gauging stations nearest each dam site are shown in Table 5.1.1 as well as in Fig. 5.1.1.

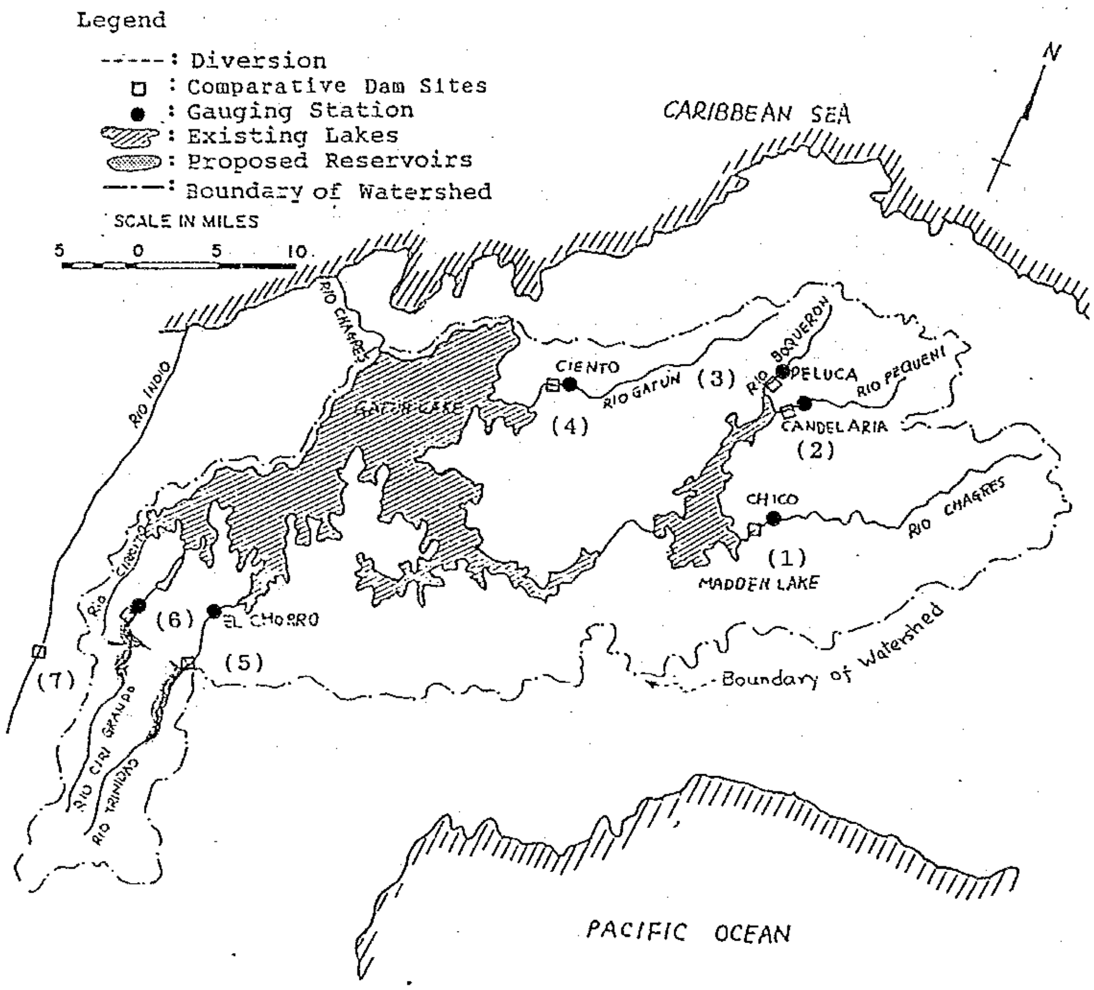


Fig. 5.1.1 Location of Rivers and Proposed New Dams

Table 5.1.1 Summary of Dam Sites and Gauging Stations

	Dam	River	Drainage Area (km2)	Gauging Station	Drainage Area (km2)
(1)	TRANCADO	Rio Chagres	425	CHICO	414
(2)	PEQUENI	Rio Pequeni	135	CANDELARIA	135
(3)	BOQUERON	Rio Boqueron	95	PELLICA	91
(4)	GATUN	Rio Gatun	125	CIENTO	122
(5)	TRINIDAD	Rio Trinidad	165	CHORRO	173
(6)	CIRI	Rio Ciri Grande	190	LOS CANONES	186
(7)	INDIO	Rio Indio	380	---	---

5.1.3 Location

(1) Trancado

A dam site has been selected in a relatively narrow part of the valley approximately 2 km upstream from where the Rio Chagres flows into Madden Lake. Chico gauging station is situated approximately 4 km up stream from this site. This site was the furthest downstream of the dam sites considered on the Chagres river. Approximately 1 km further upstream of this site there is another potential site however the lower site was selected after considering the effective use of water resources on the river. This site has the potential to supply an extremely large water yield and the dam size should be as large as possible within the engineering limits.

(2) Pequeni

A dam site has been selected in a relatively narrow part of the valley approximately 2 km upstream from where the Rio Pequeni flows into Madden Lake and is located near Candelaria gauging station. This site is located the furthest downstream of the candidate dam sites on the Pequeni river but a further 2 km upstream there is another potential site.

(3) Boqueron

A dam site has been selected in a relatively narrow a part of the valley approximately 3 km upstream from where the Rio Boqueron flows into Madden Lake and is located near Pellica gauging station. This site is located the furthest downstream amongst the candidate dam sites on the Boqueron river.

(4) Gatun

A dam site has been selected in a relatively narrow a part of the valley approximately 6 km upstream from where the Rio Gatun flow into Gatun Lake and is located near Ciento gauging station. Approximately a further 2 km downstream from this site there are other possible sites however the relative height between river bed and ridge is comparatively small and hence were not selected.

(5) Trinidad

A dam site has been selected in a relatively narrow a part of the valley approximately 9 km upstream from where the Rio Trinidad flows into Gatun Lake and is located approximately 4 km upstream from Chorro gauging station. Approximately a further 3 km downstream from this site there are other potential sites however the relative height between river bed and ridge is comparatively small and hence were not selected.

(6) Ciri Grande

A dam site has been selected in a narrow part of the valley approximately 3 km upstream from where the Rio Ciri Grande flows into Gatun Lake and is located near Los Canones gauging station. The valley is quite narrow for approximately 2 km including the gauging station site and is suitable for a dam site. The topography upstream from the dam site area is relatively flat and in particular the left bank ridge is low and so considering to prepare saddle dam.

(7) Indio

A dam site has been selected approximately 25 km upstream in a straight line from where the Rio Indio flows into the Atlantic ocean. Suitable sites for a dam of the proposed size on this river seem to be, according to the maps, very limited. If water is conveyed from the Indio reservoir into Gatun Lake using gravity water flow, a supply conduit about 10 km long would be required.

In order to make more effective usage of the basin's water resources, the reservoir low water level could be reduced by moving the dam site downstream on the river. An alternative plan would be to move the dam site upstream so that the reservoir L.W.L could be raised. Water could then be conveyed to Rio Circito instead of Gatun Lake, making it possible to shorter the length of the conduit pipe required.

5.1.4 Type of Dam

The most suitable type of dam is chosen by considering the topographical, geological and hydrological conditions at the dam site. From a topographical point of view, the shape of the valley is the most important factor in the selection. On the other hand economical considerations such as the distribution of construction materials are also very important factors. By considering the above factors it was decided that the fill type dam would be the most suitable. The materials from the canal excavation can be used as dam embankment materials.

A typical section of the proposed fill type dam is shown in Fig. 5.1.2.

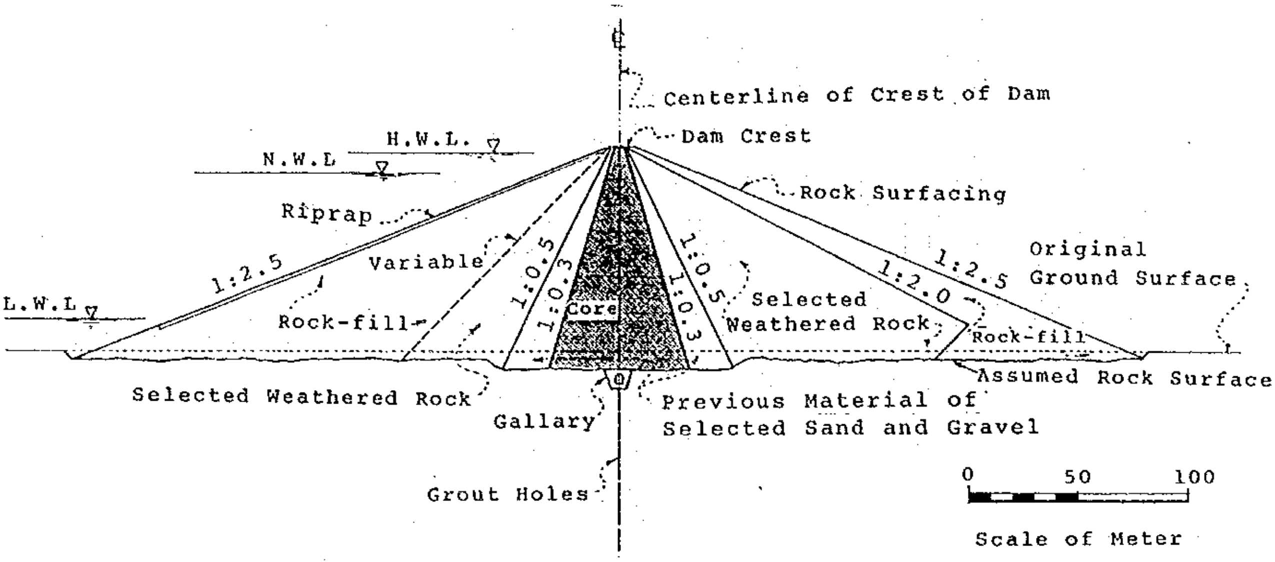


Fig. 5.1.2 Typical Section of New Dams

5.1.5 Design Criteria for Dams

The following procedures and methodology are applied to determine reservoir water surface levels and dam crest elevations.

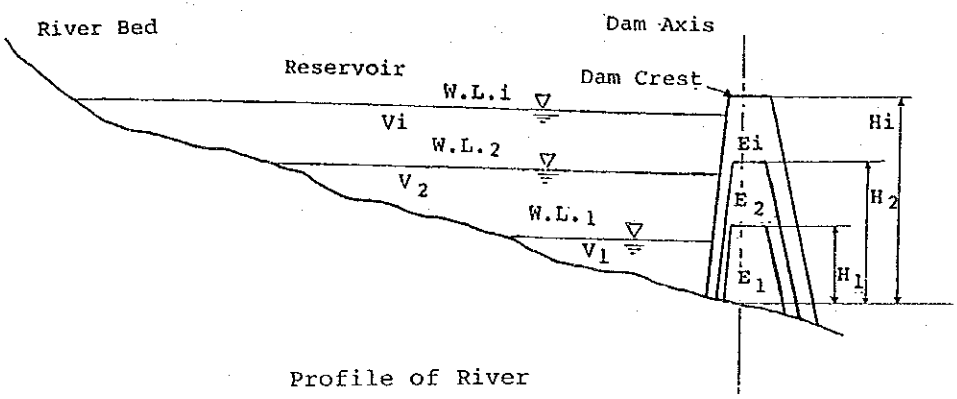
Water Demand (less than Annual Water Yield)
↓
Net Storage Capacity
↓ ←——— Sediment
Gross Storage Capacity
↓ ←——— H-V (Height-Volume) Curve
Normal Water Level (NWL)
↓ ←——— Spillway overflow depth (ungated spillway)
High Water Level (HWL)
↓ ←——— Freeboard
Dam Crest Elevation

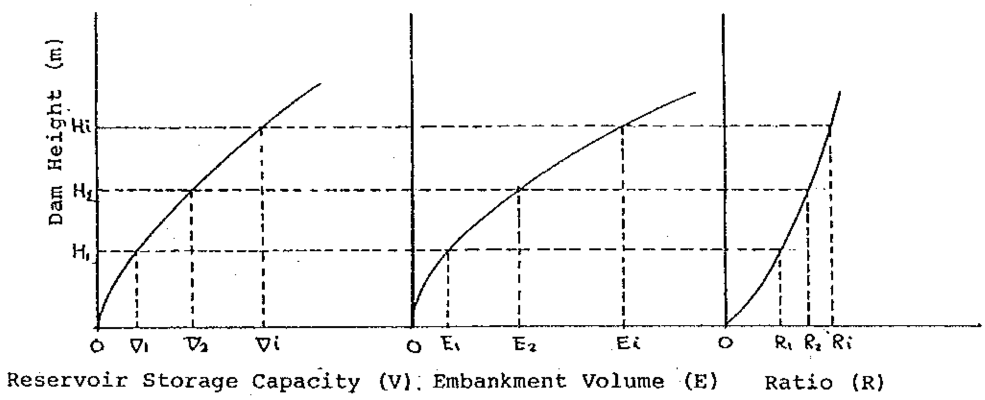
Note: H-V curves of proposed dam sites were prepared by using topographical maps of 1:50,000 scale.

5.1.6 Selected Dam Sites

A prescreening study was carried out for the seven potential dam sites in the seven major river basins. Fig. 5.1.3 shows the relation between dam height and effective storage capacities per unit dam embankment volume for each site. Ratio curve is made as follows.

(1) Dam Height H-Gross Storage Capacity (V)
(2) Dam Height H-Dam Embankment Volume (E)
(3) Dam Height H-Effective Storage Ratio R=V/E





The Figure 5.1.3 shows that Ciri Grande and Trinidad dam are the most favorably located considering the H-R curves. Effective storage ratio of Trancado is estimated to similar tendency of Pequeni Dam site because the map of Trancado was not available.

Ability of each site watershed to sustain the reservoir is adopted amount of annually runoff discharge of each site. Unite runoff amount of Gatun Lake drainage can be assumed annually at 1.77 mill.m3/km2 on average as below;

(Total annual mean discharge - Lake evaporation) ÷ Drainage Area (6593 mill.m3 - 673 mill.m3) ÷ 3339 km2 = 1.77 mill.m3/km2

Selection of the optimum dams would be confirmed after further studies in which water demand patterns, geological conditions such as the thickness of river deposits and weathered rock foundation, the strength and permeability of the bedrock and the distribution of construction materials were studied.

5.1.7 Development of New Dams

From the results of the water balance simulation for each study case, water resource development will be required. Development proposals are shown in following Tables 5.1.2 and 5.1.3.

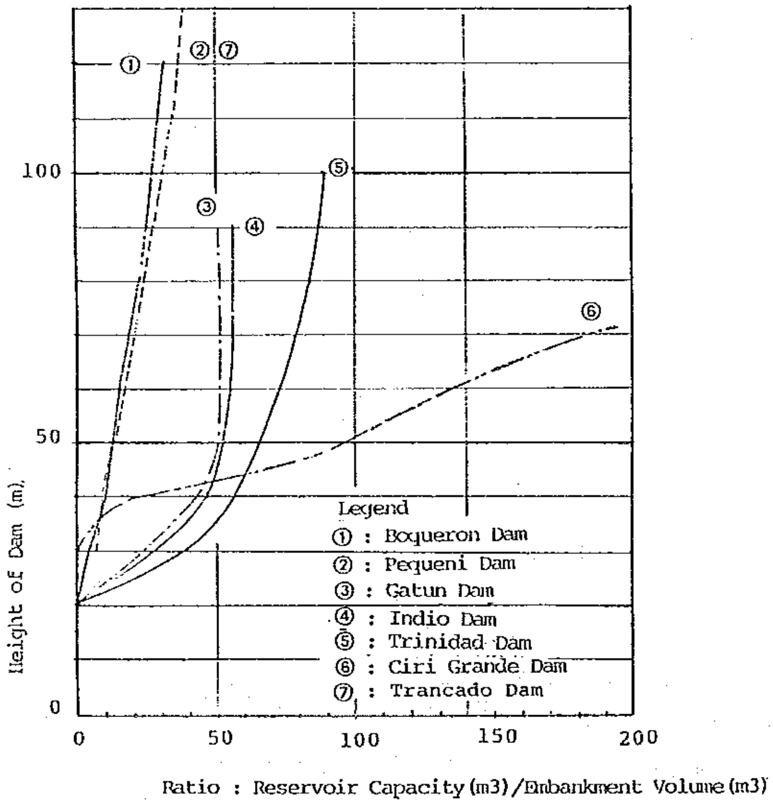


Fig. 5.1.3 Relation between Dam Height and Effective Storage Ratio per unit Dam Embankment Volume

Table 5.1.2 Water Resource Development Requirements

	L-1	L-2	L-2'	L-4	L-5	L-7	L-8	L-10	L-13	L-16
Water volume required (mill m3)	285	373	339	288	292	279	376	373	292	376

Ciri and Trinidad dams have been selected on the basis of Fig. 5.1.3 to meet the storage water volume requirements.

Table 5.1.3 Summary of New Dam Proposals

Study Case	New Dam	Drainage Area	Reservoir					Dam			
			Stor. Cap.	Sediment	N.W.L	L.W.L	H.W.L.	Crest El.	H	L	Volume
		(km²)	(mill m³)		(m)	(m)	(m)	(m)	(m)	(m)	(mill m³)
L-1, L-5, L-7, L-13, L-4	Trinidad	165	159-172	9	117	90	120	124	55	600	2.5
	Ciri	190	120	10	120	100	123	127	70	220	1.5
									Total		4.0
L-2, L-2', L-8, L-10, L-16	Trinidad	165	219-256	9	126	90	129	133	65	700	4.0
	Ciri	190	120	10	120	100	123	127	70	220	1.5
									Total		5.5

5.2 Barrier Dams

Barrier Dams are proposed for the low rise lock systems with water levels of 55' and 30' (L-3, L-6, L-9, L-11, L-12, L-14, L-15, L-17, L-18) in order to supply the water used in canal lock operations, and for the Route 10 (S-1 - S-6, S-13 - S-15) and Route 14S (S-7 - S-12, S-16 - S-18) Sea Level Canals as a means of dewatering the Canal construction area.

5.2.1 Location of Barrier Dams

(1) for the low rise lock systems with water levels of 55' and 30', and the Route 14S Sea Level canal:

Fig. 5.2.1 shows the location of the Barrier Dams for the water level EL=55', 30' and Route 14S Sea Level Canal. The following four sites have been considered based on the shape and topography of Gatun Lake and the distribution of the rivers flowing into the lake.

- A. Rio Chagres : Flowing in from the east side of the canal
- B. Rio Gatun, Rio Agua Sucia : As above
- C. Rio Trinidad, Rio Ciri Grande : Flowing in from the west side of the canal
- D. Rio Pescade, Rio Cano : As above

In order to provide the canal with an efficient supply of water, barrier dam sites have been selected so as to provide large water surface areas and a high poundage in areas where the dam length would be shortest. All Barrier dams are equipped with spillway and outlet. An outline of the proposed barrier dams is shown in Table 5.2.1.

Table 5.2.1 Proposed Barrier Dams
(Low Rise Lock Canal & Route 14S)

Dam	River	Drainage Area (km2)	Reservoir W.L. (m)	Reservoir Area (km2)	Reservoir Capacity (mill.m3)
A	Rio Chagres	1320	26.1	2.7	14
B	Rio Gatun	370	26.1	67	820
C	Rio Trinidad	780	26.1	127	1192
D	Rio Pescado	300	26.1	16	58

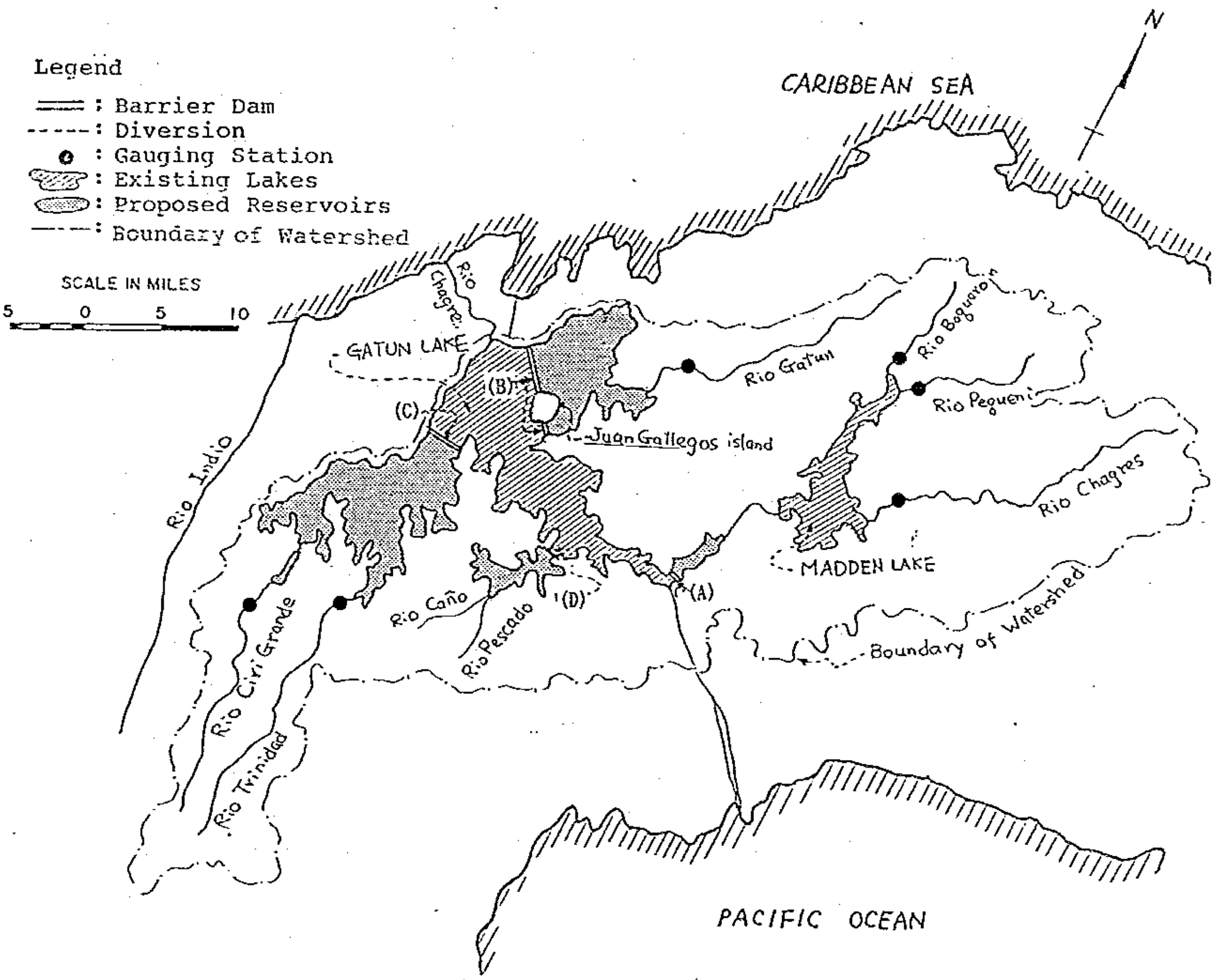


Fig. 5.2.1 Location of Barrier Dams
(Low Rise Lock Canal Systems and Route 14S)

a) Dam site A - Rio Chagres

This dam site has been selected approximately 1 km upstream from where the Rio Chagres enters the canal, at a location where the valley is relatively narrow. Gamboa is located at the point where the Rio Chagres flows into the canal. The barrier dam and its facilities (the spillway, intake and outlet) should be constructed away from the town. The reservoir surface and capacity are smallest among the proposed dams and increasing the capacity by raising the water level would present economical problems.

b) Dam site B - Rio Gatun/Rio Agua Sucia

The dam site is located downstream of the old Rio Gatun between the canal and the highway. Juan Gallegos island in Gatun Lake would be closed off by 4 barrier dams. The reservoir surface is large and the capacity is also large but the impact on the highway must be considered in the event of increasing the existing water level.

The existing railway embankment is not coincident with new barrier dams. New barrier dams are planned at the west side of the railway embankment mainly because inorder to keep the reservoir volume bigger in the enclosed area by the barrier dams. The stability of the existing embankment is also thought to be unsafe as a barrier dams.

c) Dam site C - Rio Trinidad/Rio Ciri Grande

The dam site is located downstream of the old Rio Trinidad approximately 4 km south of the canal. Gaucha and Tern islands in Gatun Lake would be closed off by 3 barrier dams. The reservoir surface area and capacity are largest of the proposed dams.

d) Dam site D - Rio Pescado

The dam site is located, in the vicinity of Manguito, downstream of the old Rio Pesado and approximately 2 km south of the canal in an extremely narrow site. The reservoir surface and capacity are relatively small compared the other proposed dams.

(2) for Route 10

Fig. 5.2.2 shows the location of Barrier dams for the Route 10 Sea Level Canal. The following three sites have been proposed based on the shape and topography of Gatun Lake and maintaining a safe distance from the sea level canal alignment.

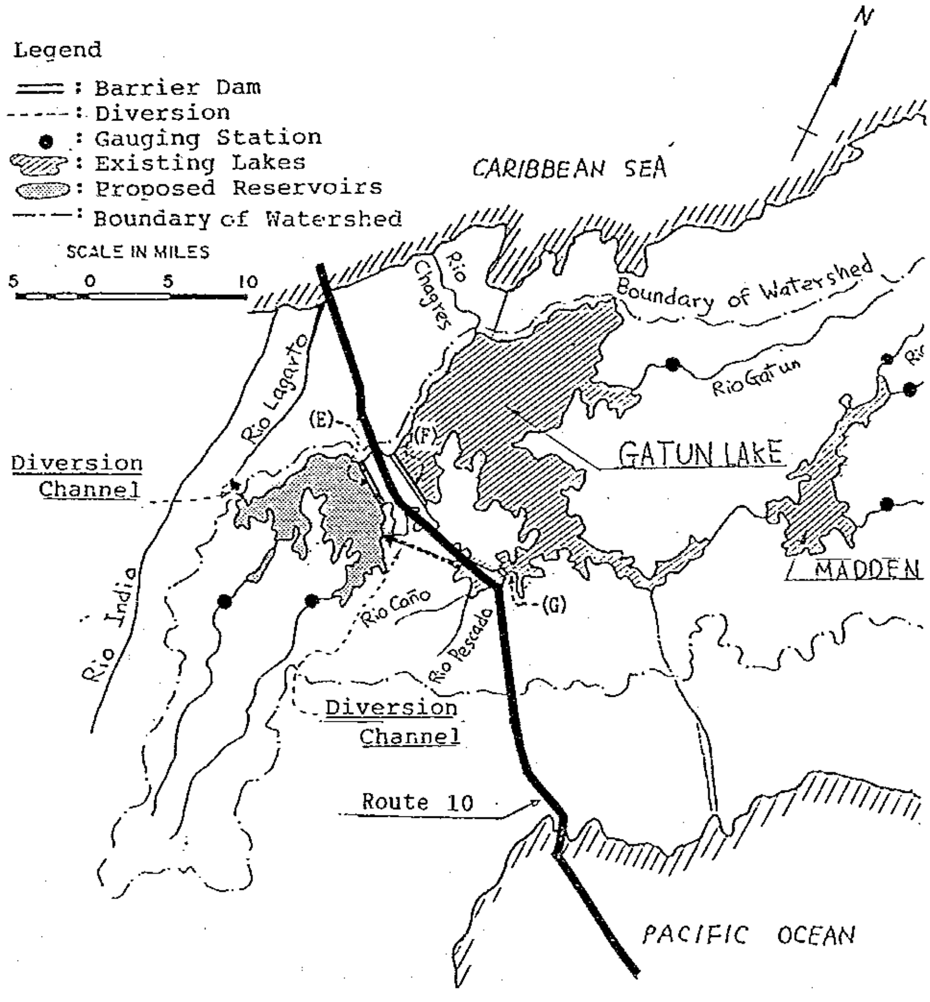


Fig. 5.2.2 Location of Barrier Dams (Route 10)

a) Dam site E

The dam site is located downstream of the old Rio Trinidad approximately 1 km south of the proposed Route 10. Los Negros and Esperanza islands in the Lake would be closed off by 3 barrier dams. The barrier dam is equipped with a spillway to ensure the safety of the dams, and a diversion conduit from the reservoir to Rio Lagorto is also proposed in order to reduce the levels to which the water could rise. After the construction of canal, concrete conduit is provided at trace of the diversion channel B, convey reservoir water into Route 10 canal between proposal tidal gates.

b) Dam site F

The dam site F is located downstream of dam site E and north of Route 10. The axis of each dam are almost parallel and each dam is separated by approximately 3 km. Remon and Bajo Island in the Lake would be closed off by 2 barrier dams. The dam site is located downstream of the old Rio Pescado approximately 7 km south of the canal, and about 1 km away to north of Route 10.

c) Dam site G

The dam site is located downstream of the old Rio Pescado approximately 7 km south of the canal, and about 1 km away to the north of Route 10.

5.2.2 Type of Barrier Dams

From an economical point of view, considering the huge crest length, relatively small difference water levels between the upstream and downstream side of the dams and dam foundation treatment are almost under water, therefore the type of dam proposed is the fill-type dam. The dam embankment materials would consist of core, filter and rockfill. The core material is decomposed rock which is made up of relatively fine grade (about 25% content passing 200# sieve). The filter material consists of well graded sand and gravel which will not suffer segregation during placement in the water. The rockfill material is coarse material including hard rock to be used as riprap. Fig. 5.2.3 shows a typical section of dam.

It is considered that there will be enough usable materials from appropriation of materials excavated from the canal, but some blending and separation will be necessary.

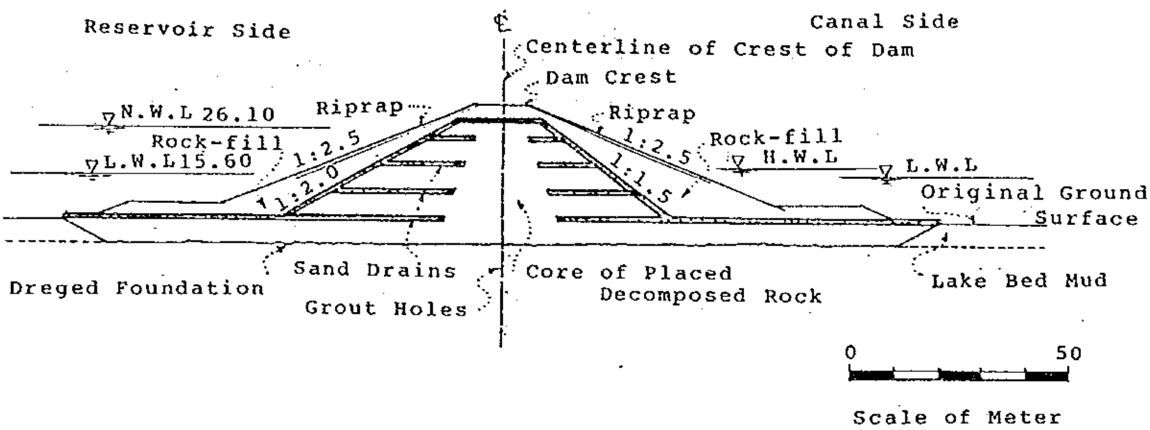


Fig. 5.2.3 Typical section of Barrier Dams

5.2.3 Design Criteria of Dam

The following procedures and methodology are applied to determine reservoir water surface levels and dam crest elevations.

Water Demand
↓ ← H-V Curve
Normal Water Level (NWL)
↓ ← Spillway overflow depth (Gated spillway)
High Water Level (HWL)
↓ ← Freeboard
Dam Crest Elevation

5.2.4 Development of Barrier Dams

From the results of the water balance simulation for each study cases, barrier dams will be required. An outline of the Barrier dams is shown in the following Table 5.2.2.

Table 5.2.2 Summary of Barrier Dams

Study Case	Dam	Drainage Area (Km^2)	Reservoir NWL (m)	HWL (m)	LWL (m)	Dam Crest EL(m)	Height (m)	Length (m)	Volume (mill m^3)
L-3, L-11	A	1,320	26.1	26.1	15.6	30	17	900	0.8
L-6, L-14	B-1	370	26.1	26.1	15.6	30	29	4,100	11.3
L-9, L-17	B-2						20	520	0.6
	B-3						20	100	0.2
	B-4						20	100	0.2
	C-1	780	26.1	26.1	15.6	30	30	1,800	4.3
	C-2						27	1,100	1.8
	C-3						27	500	0.7
	D	300	26.1	26.1	15.6	30	20	500	0.4
								Total	20.3
L-12, L-18	A	1,320	26.1	26.1	8.1	30	17	900	0.8
L-15	B	370	26.1	26.1	8.1	30	29-20	4,820	12.3
	C	780	26.1	26.1	8.1	30	30-27	3,400	6.8
	D	300	26.1	26.1	8.1	30	20	500	0.4
								Total	20.3
Route 14S (S-7 - S-12,	A	1,320	26.1	26.1		30	17	900	0.8
S-16 - S-18)	B	370	26.1	26.1		30	29-20	4,820	12.3
	C	780	26.1	26.1		30	30-27	3,400	6.8
	D	300	26.1	26.1		30	20	500	0.4
								Total	20.3
Route 10 (S-1 - S-6,	E	685	26.1	26.1		30	25	4,350	4.5
S-13 - S-15)	F	---	26.1	26.1		30	27	4,900	5.5
	G	---	26.1	26.1		30	20	880	0.7
								Total	10.7

5.3 Anchorages, Moorings and Breakwaters

5.3.1 Introduction

Anchorages are required at each end of a canal so that ships waiting for their turn to transit the canal may anchor, if necessary. Within the canal and its immediate approaches moorings are required for ships which have been delayed and cannot proceed. Buoyed moorings are appropriate in some locations but the majority would be for along-side berths both at locks and throughout the length of the canal.

The benefits from the breakwaters at the entrances to the canal have been modified over the years by the increasing size of ships wishing to transit the canal. Originally, they provided sheltered anchorage for shipping as well as shelter for the locks which would otherwise have been exposed to action from waves generated offshore. Those waves are potentially much larger than can be generated within the area sheltered by the breakwaters. The proportion of ships using the canal which require shelter while they wait to enter is predicted to decrease (See Analytics predicted ship mix for 2010 in Sinbol's Status of the present canal) so that the prime function of the breakwaters has become to protect the immediate approaches to the canal to minimize wave effects on ship handling and to protect the lock gates.

5.3.2 Anchorages

Until predictions of canal traffic become available which show not only the number of ships likely to use the canal but also their distribution in size, an approximate number of berths in the anchorages has been estimated as follows.

Recent PCC Annual Reports e.g. 1989, show the number of transits to be almost equally split between the two directions. It has been assumed that this situation will continue.

The mix of ships transiting the canal has been assumed to be that predicted by Analytics (referenced above) for 2010. Maximum canal capacity with such a mix of ships has been estimated as 26,000 per year for a 4-lane locked canal and 19,000 for a single lane sea level canal. (See Annex to this report.) These capacities represent an average of 72 and 52 transits per day respectively. A figure of 72 transits per day has been chosen to estimate the anchorage area required.

Of the 72 vessels arriving each day, most will plan their arrival to coincide with their tine of passage and will not anchor. It is reasonable to assume that this may not be possible for half of the arrivals so that, on average, 18 ships with require anchorage at each end of the canal. To this number a peaking factor of 1.3 has been applied to allow for grouping and random arrival. An anchorage sufficient in area for 24 ships will be required at each end of the canal. No allowance has been made for ships which may wish to delay their departure from the canal as it is considered that this number will be small.

The area required for anchorage will depend upon the site of ships and anchoring positions should be set out to accommodate a range of vessel sizes for a probable mix of ships.

The swinging radius comprises the sum of the scope of the anchor chain and the ship's overall length. For this purpose the scope of chain is assumed to be six times the depth of water (Technical standards for port and harbor facilities in Japan, 1980. Overseas Coastal Area Development Institute of Japan.) and the spacing of anchoring positions is taken as 2.5 times the swinging radius. This spacing will ensure clearance between ships allowing for variations in length of chain and the unlikely event of adjacent vessels lying in opposite directions from their anchors. The space required for 24 positions amounts to 25 km2 and would be generous should the ships be smaller than assumed. For the two lane sea level canal the capacity could be 80% greater and the anchorage area would become 45 km2.

Table 5.3.1 Anchorage Area Required for a Single Lane Canal

Ship size (DWT)	LOA (m)	Draught (m)	Water depth (m)	Radius (m)	No of ships	Area occupied (km2)
60,000	277	12	15	367	16	13.4
100,000	295	17	21	421	2	2.2
150,000	316	19	24	460	2	2.6
250,000	372	22	27.5	537	3	5.4
300,000	394	23	29	568	1	1.1
				Total		24.7

The existing designated anchorage area outside the breakwaters at Limon is about 26 sq km and appears to have depths of up to 100 feet (30.5m) and would be adequate for the largest vessels. In the Pacific, the area is larger (58 sq km) but shallower (17m). A space for about eight of the larger ships would need to be dredged to depths ranging from 21 to 29m. A suitable location for the deeper area would be adjacent to the fairway into the canal.

5.3.3 Moorings

Moorings are needed for ships in the canal and its immediate approaches if their passage is interrupted and sufficient should be provided to accommodate as many ships as may be unable to escape from the restricted channel.

As an example consider ships approaching the canal from the Atlantic. Until they pass the breakwater heads they will be able to turn from the channel if an emergency arises but, once inside the breakwaters, a large ship's freedom to maneuver will be restricted by lack of depth and space. The maximum number of ships will be involved if an emergency which prevents passage should occur at the locks. Provision needs to be made to moor all ships which may have entered the restricted channel within the breakwater heads.

Assuming there to be two existing and two new lanes of locks with a combined frequency of 3.02 ships/hr and that the steaming time from the breakwater heads to the locks is 1.08 hrs; there would be 3.02 x 1.08 + 1 = 4.26 (say 4) ships in the inner channel at any time. Thus if all the locks were to be closed, four moorings would be required. In practice, it is unlikely that both sets of locks would be out of action at the same time and only two ships will need to moor.

Similar reasoning may be applied to each end of all the locks as follows. Between Gatun and Pedro Miguel (Miraflores in the case of the new locks) the Culebra Cut will govern the number of ships needing to moor. For those sailing towards the Atlantic, all within the cut would need to stop but, as there is space for them to anchor in the lake, no moorings would be required. For southbound ships, those already in the Cut would be affected if either Pedro Miguel or the new locks at Miraflores were to be shut unexpectedly. While moorings could be provided close to the locks, there will be, for safety reasons, emergency moorings along the banks of the Cut and these could be used provided ships using the operative locks could pass the moored vessels in safety. This will depend upon the dimensions of the canal cross-section and the size of ships involved. The numbers given in the table below assume that all affected ships will moor close to the locks. Moorings for northbound ships at both sets of locks will be determined by the factors described for Gatun.

Table 5.3.2 Mooring Requirements

Location	Direction	No. of moorings	Comment
Gatun	South	2	--
Gatun	North	8	Ships will anchor in lake
Pedro Miguel	South	3	Ships could moor in canal
Pedro Miguel	North	1	--
Miraflores	South	3	Ships could moor in canal
Miraflores	North	3	--

Moorings within the canal would comprise bollards at regular intervals along the banks while at the locks mooring dolphins would be preferred.

5.3.4 Breakwaters

Protective breakwaters at both ends of the canal need only be sited to shelter the immediate entrance from severe wave action and cross currents, both of which would hamper safe navigation into and out of the canal. Limited anchorage for small ships would be possible within such a configuration but, until detailed predictions of ship size and number are available, the area needed for anchorage cannot be determined. The existing arrangements at Limon and the Pacific entrance appear adequate for the foreseeable demands.

At the entrance to a sea level canal on Route 10, natural protection appears to be limited and breakwaters will be required. The distance offshore of the breakwater heads should be sufficient to give shelter to ships during the final stages of their stopping maneuver. For VLCC's this distance should be about 6 km. The location of the breakwaters will depend upon local bathymetry and topography but their roots might be approximately 3 km either side of the channel so that an area of about 20 sq km would be enclosed. Particular attention will be required in assessing the changes to the local environment resulting from the introduction of the breakwaters and their possible adverse effects on the neighboring coastline.

5.3.5 Conclusions

Anchorages should be provided at each end of the canal to accommodate ships awaiting their turn to enter the canal. The estimated areas required amount to 17 sq km at each end of the locked and single lane sea level canals. A two lane sea level canal would need about 35 sq km of anchorage at each end. In view of the size of the majority of vessels expected to use the canal the anchorages need not be protected. Water depths within the anchorage area may vary but some deep-water areas will be required for the larger vessels.

Moorings should be provided in the approaches to all the locks. Numbers vary depending upon the number of ships which might be in areas of restricted maneuverability when an emergency arises but would not exceed three in any location. In general, mooring dolphins are to be preferred as they would minimize obstruction to the movements of other ships.