3-2 Features of the phased plans

3-2-1 Transit conditions

Different phased plans are studied to determine what transit conditions are secured compared with those after the completion of the First Stage Project.

(1) Size of transit vessels

The size of transit vessels projected for the First Stage Project is around 150,000 DWT tanker fully laden for the northbound channel and 50,000 G/T container vessel and around 300,000 DWT tanker in ballast for the southbound channel. The Canal section was designed for these vessels sizes under the Second Stage Project.

Plan 0 is intended for expanding only the section Km16–32.5 to meet the demand for the time being, with no work on other sections. Accordingly, an insufficient area ratio will occur at part of the channel, thus reducing the area ratio of 4.6 projected for around 300,000 DWT tankers in ballast on the west channel. This is probably unavoidable if Plan 0 is regarded as an extension of the First Stage Project.

With the exception of Plan 5, the phased plans are designed to use the existing Port Said Channel as the western channel in the section Km0–16. Accordingly, it is impossible for vessels with more than 11.5m (38') in draft to transit the Port Said Channel. Consequently, those southbound vessels exceeding the draft have to use the New Port Said Bypass while it is not in use by northbound vessels. In each phased plan therefore around 300,000 DWT tankers in ballast and 50,000 G/T container vessels may be regarded as the largest southbound vessels.

(2) Transit scheme

As the transit scheme under the Second Stage Project is to be studied in detail in Part VII, it is sufficient here to ascertain the difference between various transit conditions under the phased plans.

As the method of transit after the completion of the First Stage Project is to run one northbound convoy (non-stop) and two southbound convoys (S-1 convoy will lay to at the Great Bitter Lake and S-2 convoy at the Ballah Bypass while the northbound convoy passes), the transit method under the phased plans is proposed on the following principles:

1 The northbound convoy transits the Canal in non-stop.

2 For southbound convoys, non-stop transits are to be made available as much as possible by doubling the Canal.

The traffic diagram of each phased plan based on the above principles may be prepared as Figs. 6-3-2 – 6-3-8. The diagrams are based on the following premises:

a) The average speed of northbound vessels is to be 13km/h and southbound vessels 14km/h.
b) Transit vessels are to maintain an interval of 10 minutes.
c) Transit hours are to be shared equally by northbound and southbound vessels.

d) Transit hours are to be based on a 24-hour cycle.

e) Waiting sections are confined to the Ballah Bypass and the Great Bitter Lake.

Table 6-3-1 shows the allocation of navigable time and waiting hours under each phased plan.

Under each plan the navigable hours increase compared with the current situation (after the First Stage Project). With it, the navigable time period is 14.2 hours. They increase, however, to 15.8 hours in Plan 0, 18.0 hours in Plan 1, 18.8 yours in Plan 2, 19.9 hours in Plan 3, 21.3 hours in Plan 4 and finally to 24 hours in Plan 5.

Table 6-3-1 Comparative Characteristics of the Phased Plans

	Transit Capacity		Number of Convoys	Transit Hours		Waiting Hours/Ship					Navigable Time Duration
						South-bound		North-bound			
	South-bound	North-bound		South-bound	North-bound	Average	Waiting Convoy	Average	Waiting Convoy	Average	
	Ships/day			hours		hours		hours		hours	hours
Existing (After 1st Stage)	S-1 31 S-2 11	42	3 N : 1,S : 2	S-1 19.88 S-2 19.05	12.49	8.16	S-1 8.28 S-2 7.45	0	0	4.08	14.16
Plan 0	S-1 41 S-2 6	47	3 N : 1,S : 2	S-1 23.22 S-2 17.55	12.49	10.07	S-1 10.72 S-2 5.95	0	0	5.04	15.79
Plan 1-1	54	54	2 N : 1,S : 1	25.59	12.49	13.99	13.99	0	0	7.00	18.00
Plan 1-2	S-1 45 S-2 9	54	3 N : 1,S : 2	S-1 20.60 S-2 11.60	12.49	7.50	S-1 9.00	0	0	3.75	18.00
Plan 1-3	54	54	2 N : 1,S : 1	11.60	12.49	0		0		0	18.00
Plan 2	S-1 36 S-2 18	56	3 N : 1,S : 2	S-1 21.01 S-2 11.60	12.49	6.39	S-1 9.41	0	0	3.19	18.82
Plan 3	60	60	2 N : 1,S : 1	11.60	12.49	0		0		0	19.94
Plan 4	64	64	2 N : 1,S : 1	11.60	12.49	0		0		0	21.34
Plan 5	144	144	2 N : 1,S : 1	11.60	12.49	0		0		0	24.00

It is possible to reduce the waiting time for the convoys in Plans 1-2, 1-3, 2 ~ 5 compared with the current condition. Though a reduction in even one hour per vessel cannot be realized in Plans 1-2 and 2, the average waiting time will be nil because of non-stop operation for both southbound and northbound convoys in Plans 1-3 and 3 ~ 5. On the other hand, waiting time will increase in Plans 0 and 1-1, as it will be greater for southbound convoys in proportion to the increase in the transit capacity.

As has been described, the creation of the west channel adjacent to the New Port Said Bypass is not planned prior to the stage of a complete two-lane canal in Plan 5. Accordingly, those southbound vessels of over 11.5m in draft have to use the east channel prior to or after the use by northbound vessels. Fig. 6-3-9 shows the current convoy diagram under this condition.

Assuming that southbound vessels enter the east channel after northbound vessels passed HM100 on the Port Said Approach Channel, about 1.5 hours of the navigable time duration can be secured. This navigable time duration seems to be sufficient to cope with large-sized southbound vessels making transits in 1981. In Plan 0 this navigable time duration can hardly be secured as shown in Fig. 6-3-10. In Plan 1-1 large-sized southbound vessels have to pass the Km16-point by using the east channel before northbound vessels pass through the New Port Said Approach Channel (east channel) as shown in Fig. 6-3-11. Further, these large-sized southbound vessels have to wait at the Ballah By-pass for northbound vessels to pass.

In Plan 2, when those vessels in the last half of a southbound convoy depart, northbound vessels will have passed through the New Port Said Bypass and the east channel of the Port Said Approach Channel. Accordingly, non-stop transits will be possible for large-sized southbound vessels if they depart from the Outer Waiting Area and proceed through the east channel of the Approach Channel after general cargo vessels departed from the Port Said Harbour persuant to the current method of transit (Fig. 6-3-12).

In other words, if precedence is given to the expansion of the north section of the canal as in Plans 0 and 1-1, it will be difficult to secure the navigable time duration for large-sized southbound vessels. Further, it will result in disadvantages such as the necessity of making a complicated adjustment to the method of transit and of allocating a part of the navigable time duration for northbound vessels to large-sized southbound vessels.

Existing (After 1st Stage)

Cycle 24 hrs 3 convoys a day

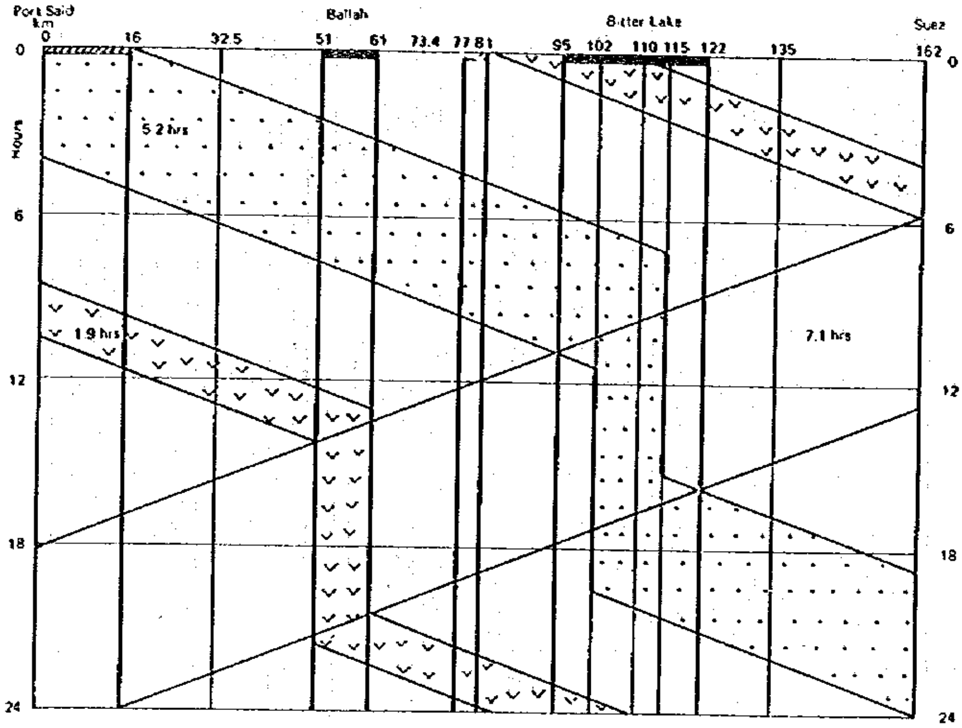


Fig. 6-3-2 Traffic Diagram (1)

Plan. 0

Cycle 24 hrs 3 convoys a day

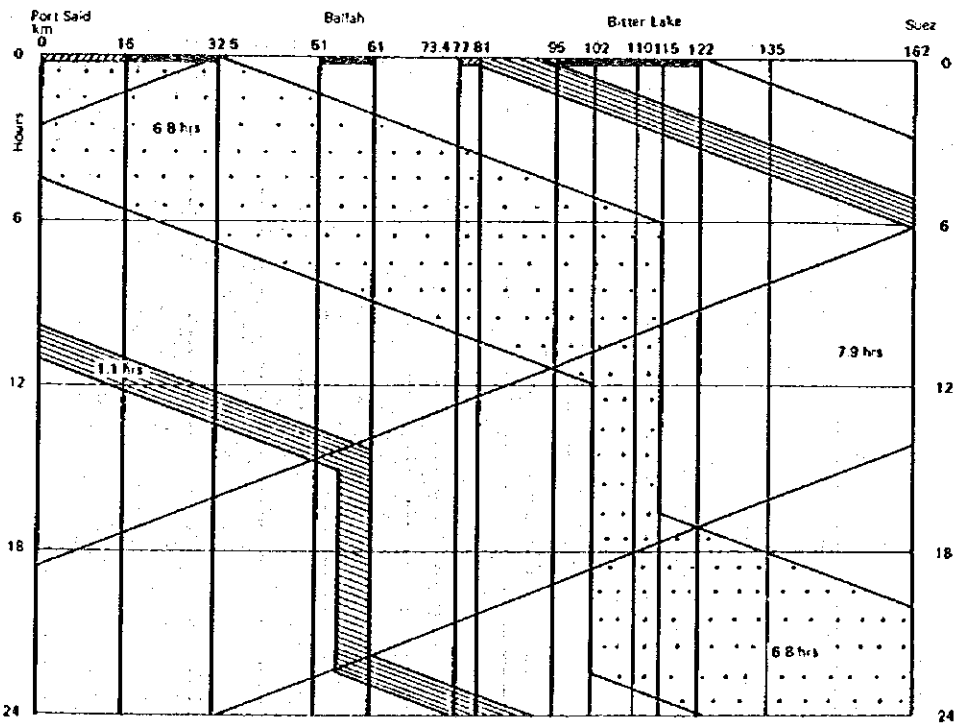


Fig. 6-3-3 Traffic Diagram (2)

Plan 1-1

Cycle 24 hrs 2 convoys a day

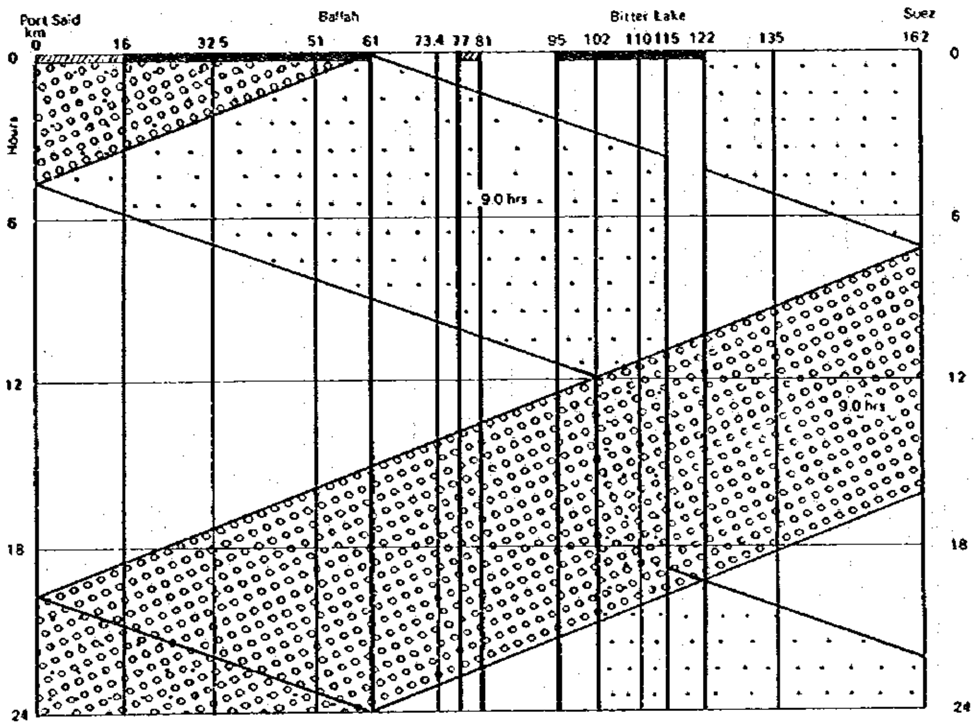


Fig. 6-3-4 Traffic Diagram (3)

Plan 1-2

Cycle 24 hrs 3 convoys a day

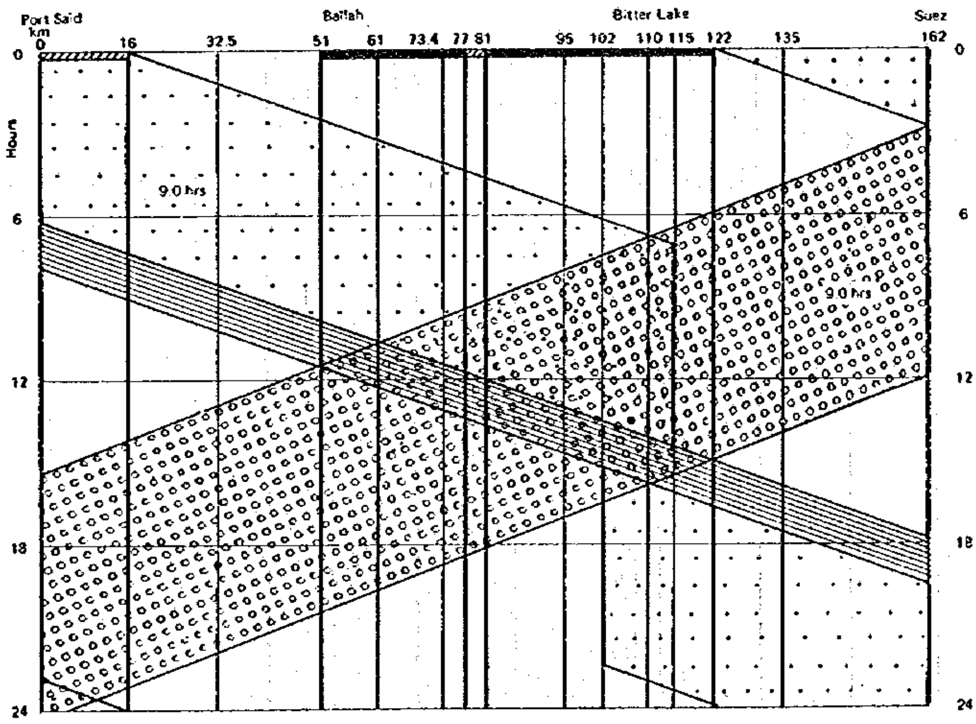


Fig. 6-3-5 Traffic Diagram (4)

Plan 1-3

Cycle 24 hrs 2 convoys a day

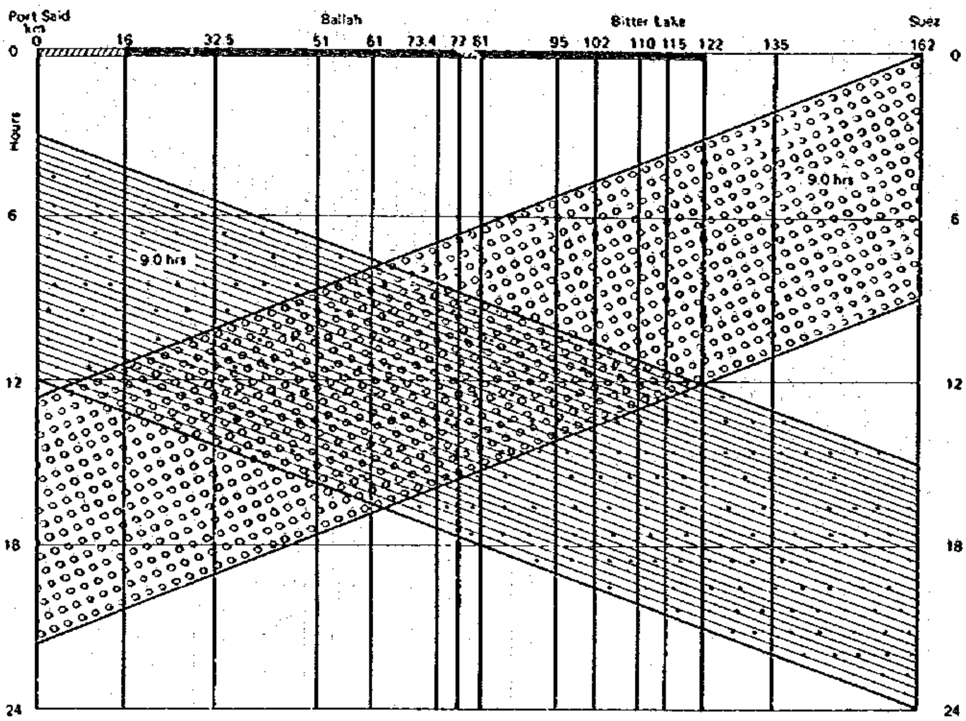


Fig. 6-3-6 Traffic Diagram (5)

Plan – 2

Cycle 24 hrs 3 convoys a day

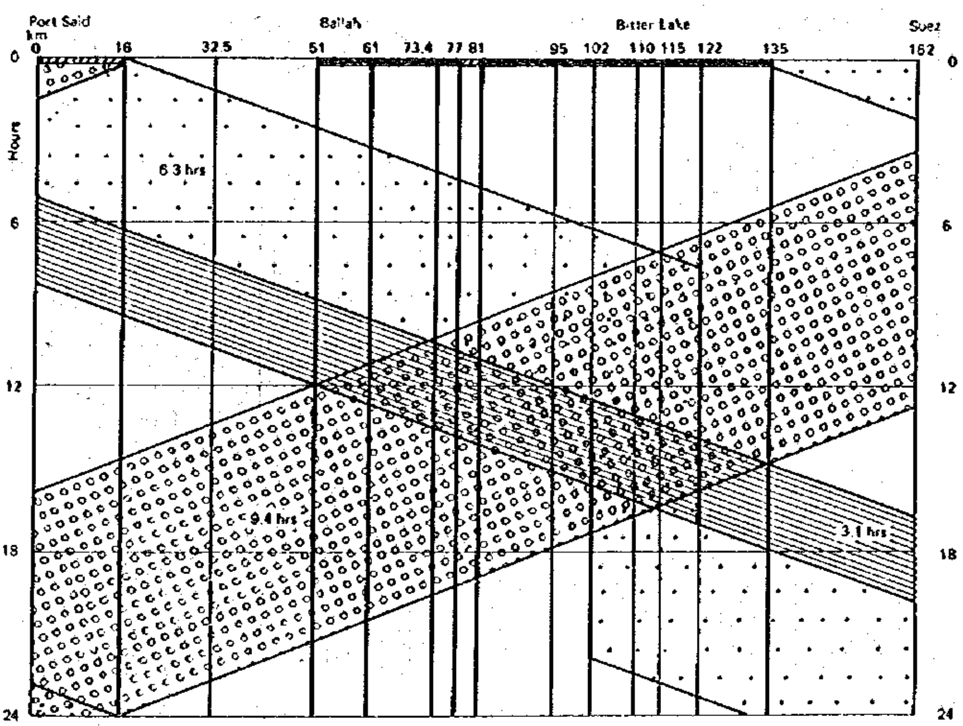


Fig. 6-3-7 Traffic Diagram (6)

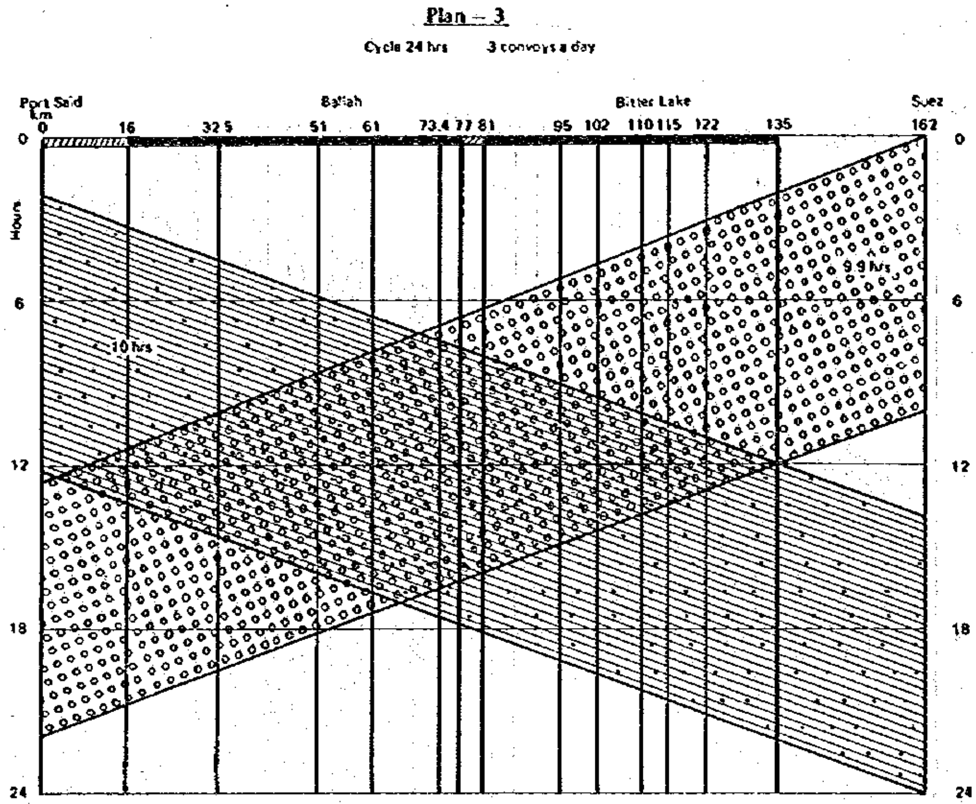


Fig. 6-3-8 Traffic Diagram (7)

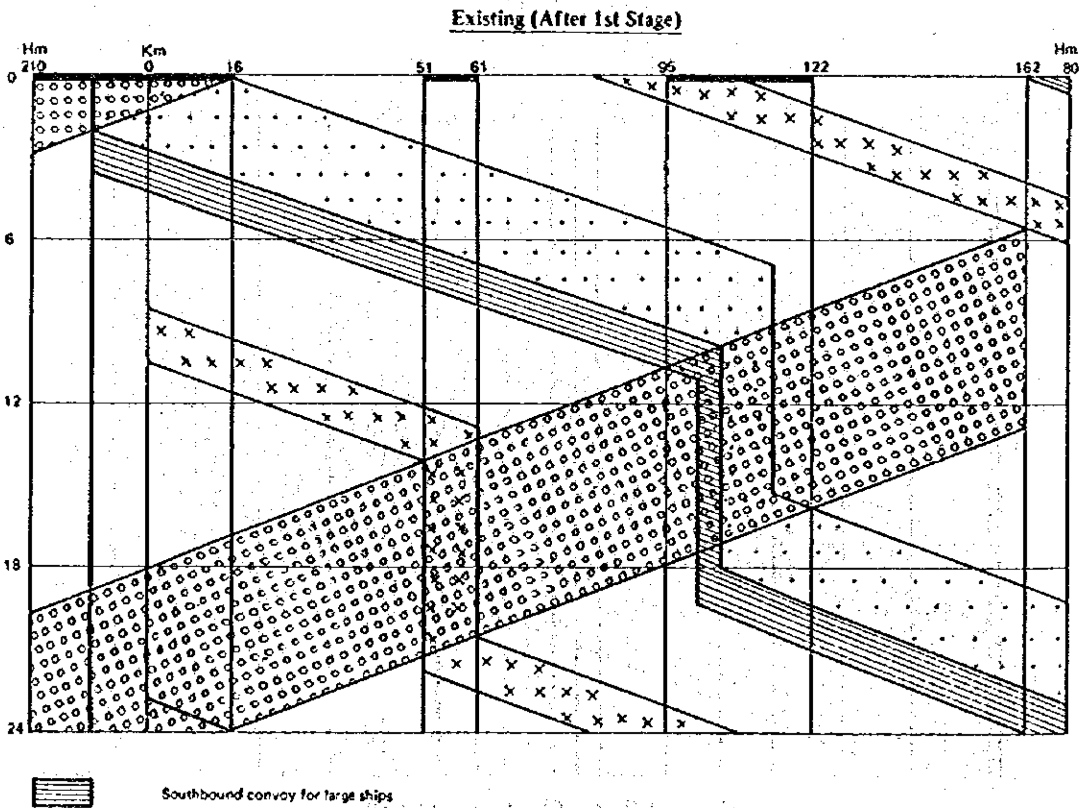


Fig. 6-3-9 Traffic Diagram (8)

Plan 0

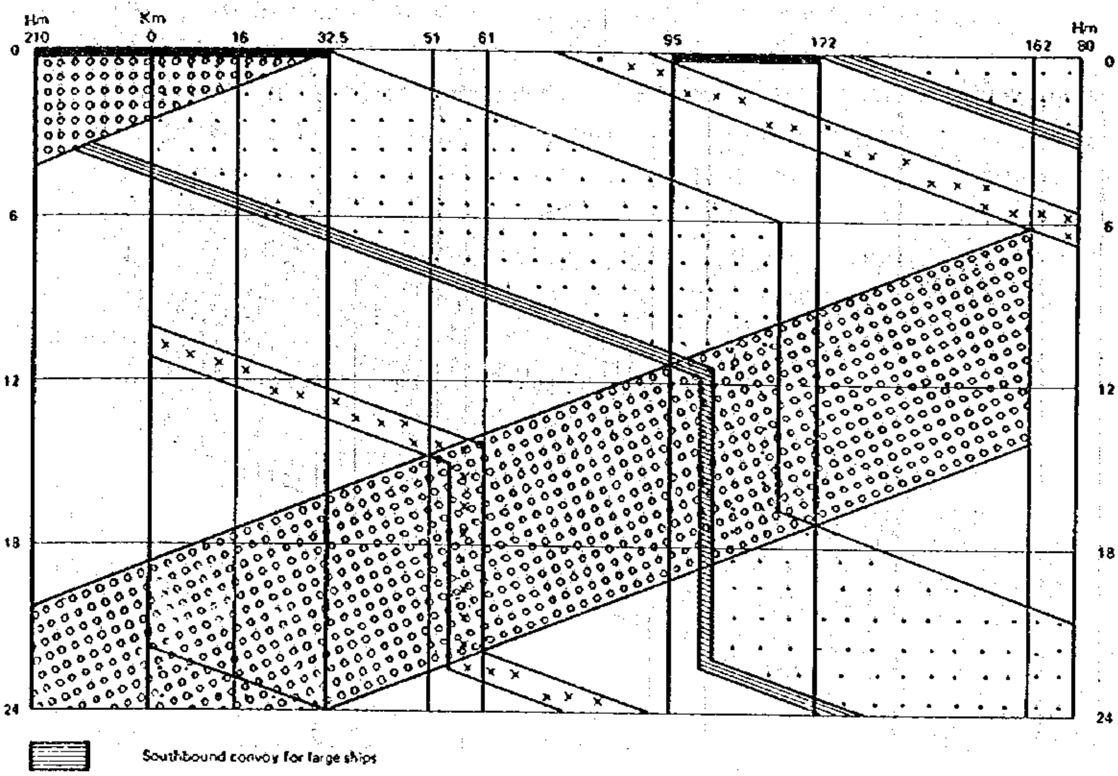


Fig. 6-3-10 Traffic Diagram (9)

Plan 1-1

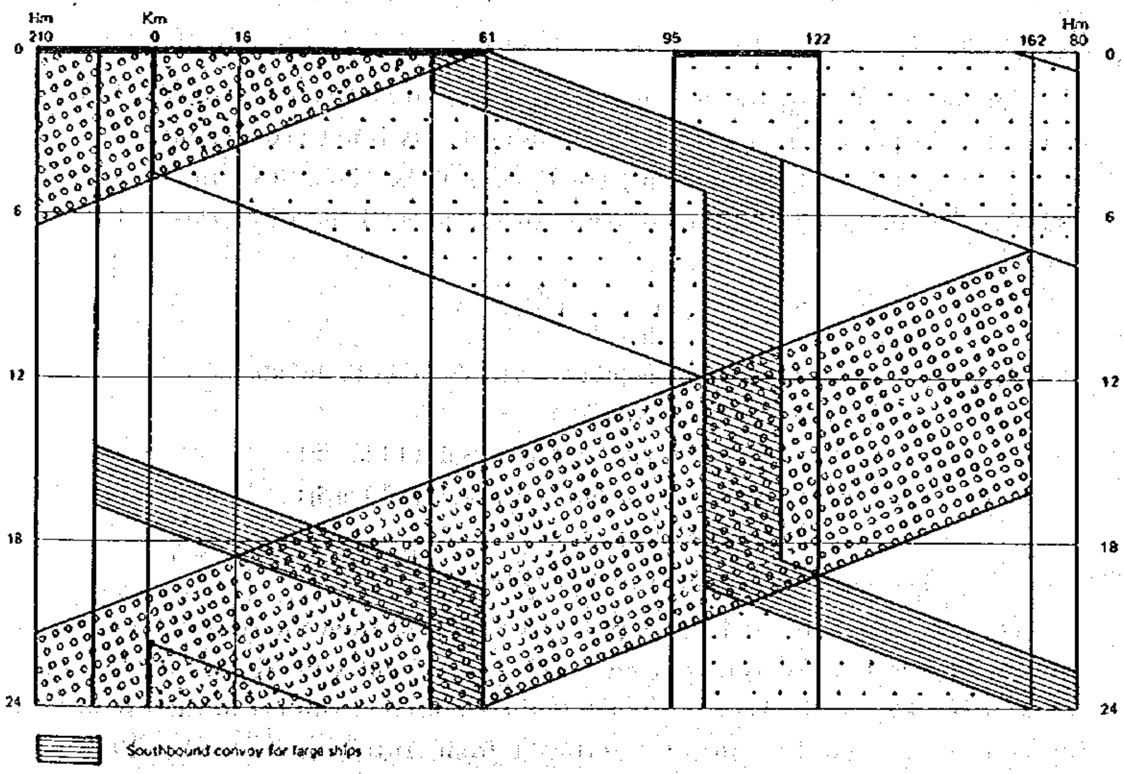


Fig. 6-3-11 Traffic Diagram (10)

Plan 2

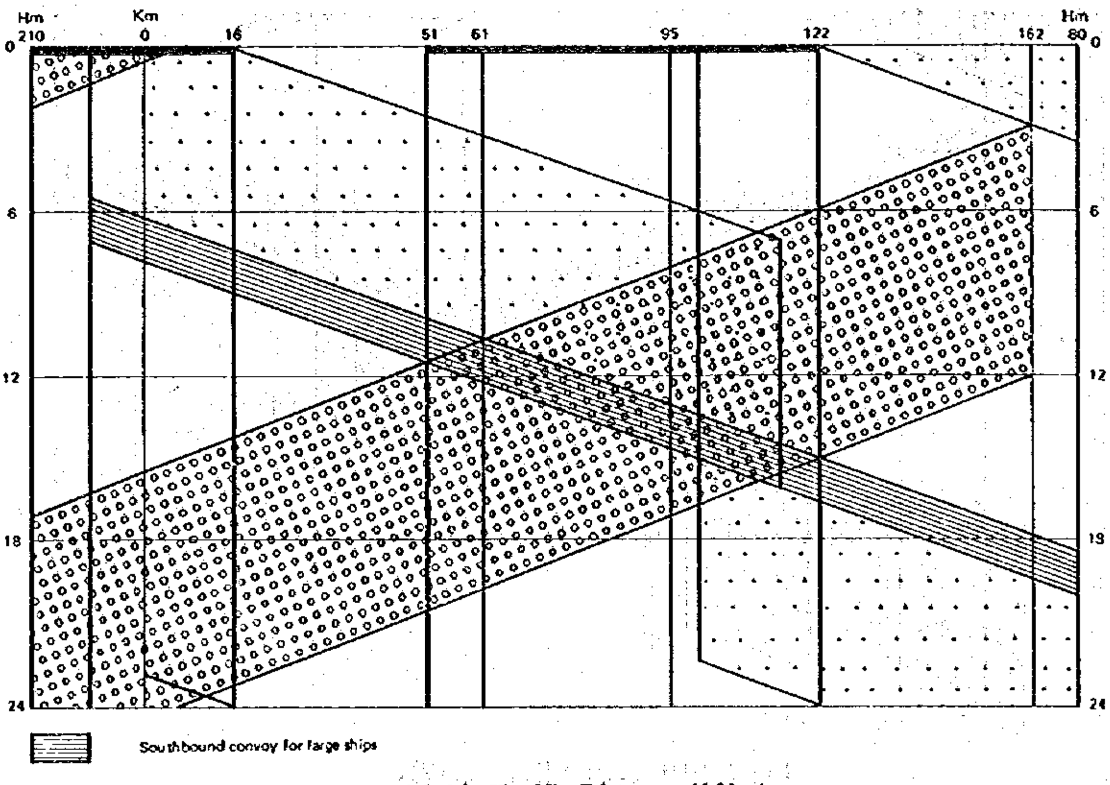


Fig. 6-3-12 Traffic Diagram (11)

(3) Transit capacity

For the transit capacity, as it is sufficient here to ascertain the difference in evaluation among the phased plans, a theoretical transit capacity is to be computed.

The transit capacity under each phased plan may be obtained by the equation below assuming that the navigation time duration of southbound and of northbound transit are equal.

$$N = \left\{ C - \left(\frac{1}{Vs} + \frac{1}{Vn} \right) \times L \right\} / \quad T \qquad (6.7)$$

Here, N : transit capacity (number of vessels for both directions)

C : transit cycle (24 hours)

Vs: average speed of southbound vessels (14 km/h)

Vn: average speed of northbound vessels (13 km/h)

L : Longest single-lane section

T : average time interval between ships

The transit capacity under each plan was computed from the equation 6.7, assuming that the average time interval between vessels is 10 minutes for the standard vessel. The Rules of Navigation specify a 5–20 minute time interval, according to the size of vessels. However, as the actual record of a fortnight from August to September 1979 was, in average, 10 minutes, it was adopted as the interval for the standard vessel.

Table 6-3-2 shows the theoretical transit capacity under each plan.

The current transit capacity of 84 vessels per day for the standard vessel may be increased by 10 to 94 in Plan 0. Plan 1s will have the same longest single-lane section of Km 122–162, so the transit capacity will be 108 vessels per day.

In Plan 2, as the single-lane section of Km 16–51 is a little shorter than that of Plan 1, the capacity will be 112 vessels. It will be 120 in Plan 3 and 128 in Plan 4, and finally free transit will be possible in Plan 5, and the capacity will be doubled to 288.

Table 6-3-2 Theoretical Transit Capacity (Standard Ship)

Plan	Capacity (ships/day)	Plan	Capacity (ships/day)
Existing (After 1st Stage)	84	Plan 1-3	108
		Plan 2	112
Plan 0	94	Plan 3	120
Plan 1-1	108	Plan 4	128
Plan 1-2	108	Plan 5	288

3-2-2 Quantity and cost of construction

Table 6-3-3 shows the quantity and the cost of construction obtained from Table 9-4-1. As regards to the quantity of works by category, the amount of dredging will be 68 million m³ in Plan 0. Of Plan 1, Plan 1-2 will have the smallest at 142 million m³ and Plan 1-3 the largest at 294 million m³ followed by Plan 1-1 at 159 million m³. It will be 178 million m³ in Plan 2, 329 million m³ in Plan 3 and 368 million m³ in Plan 4. Finally it will be 556 million m³ in Plan 5 which completes the expansion to two lanes.

Table 6-3-3 Construction Cost of Phased Development Plans

(As of 1979)

	Construction Work			Construction Cost				Remarks
	Dry Excavation	Bank Works	Dredging	Dry Excavation	Bank Works	Dredging	Total	
	10^6 m³	Km	10^6 m³	10^6 $	10^6 $	10^6 $	10^6 $	
Plan 0	14.0	28.2	67.9	19.5	22.1	42.9	84.5	
Plan 1-1	48.0	67.4	159.3	68.7	50.7	124.9	244.3	
Plan 1-2	99.0	75.8	141.8	148.3	52.5	187.1	387.9	
Plan 1-3	147.0	143.2	293.6	213.9	103.2	297.6	614.7	
Plan 2	99.0	75.8	177.5	148.3	52.5	240.9	441.7	
Plan 3	147.0	143.2	329.3	217.0	103.2	351.4	671.6	
Plan 4	154.0	166.3	367.8	231.7	126.0	409.5	767.2	
Plan 5	226.0	233.9	555.8	336.9	173.1	634.2	1,144.2	

Note: 1) These costs exclude the procurement cost for tugboats and navigation aids.
2) The bank works consist of the demolition, removal and construction of new revetment.
3) The dry excavation includes the removal of the existing railway and siphon pipes.

For dry excavation, the amount will be 14 million m^3 in Plan 0. Of Plan 1, it will be the smallest in Plan 1-1 at 48 million m^3, 99 million m^3 in Plan 1-2 and 147 million m^3 in Plan 1-3. Further, it will be 99 million m^3 in Plan 2, 147 million m^3 in Plan 3 and 154 million m^3 in Plan 4. Finally, it will be 226 million m^3 in Plan 5, equivalent to about 36% of the total amount of dredging.

The construction cost do not include related equipment of navigation aids and tugboats.

The construction costs under each plan is estimated to be US$85 million in Plan 0, which constitutes the smallest figure. Of Plan 1, the cost is expected to be US$244 million in Plan 1-1, US$388 million in Plan 1-2 and US$615 million in Plan 1-3, or 2.5 times that in Plan 1-1. Further, it is estimated to be $442 million in Plan 2, US$672 million in Plan 3, US$767 million in Plan 4 and US$1,144 million in Plan 5.

3-3 Comparison of Phased Development Plans

3-3-1 Comparison by Cost-Benefit Analysis

This section is intended to compare the phased plans by cost-benefit analysis. As the purpose of comparison here is only to ascertain the difference among the phased plans, cost and benefit are defined as follows:

(1) Costs

Costs are to be only those shown in Table 6-3-3, excluding those for maintenance, operation and administration as they are estimated to be about 2% of the construction costs.

The plan of yearly investment is based on the assumptions given below:

a) The Second Stage Project is to commence at the beginning of 1981, allowing six months for preliminary works prior to the commencement of site works.
b) Annual amount of dredging is assumed to be 60 million m^3, in every phased plan.
c) Dry excavation and the construction of revetments are to proceed without interfering with dredging.
d) Yearly investment is to be made in keeping pace with dredging.

(2) Benefits

Additional revenue derived from an increase in capacity resulting from the Second Stage Project are included. The benefits from the reduction in transit hours for Canal users resulting from the expansion to two lanes (reduction in waiting hours for southbound convoys) are also to be adopted. The reduction in waiting hours at both ends of the Canal brought by completely doubled Canal is also counted as benefit.

These benefits are to arise one year after the completion of construction under each phased plan and are to remain at the same level after the capacity reached under each plan. Computation of benefits arising from increased revenue is based on the principles given below.

a) As regards to projected vessels for the computation of an increase in revenue, a 10,000DWT general cargo vessel is to be the representative size, in the light of the recent transit record. Though the average size of non-tankers is 12,000 DWT, as this category includes bulk carriers, the size of 10,000 DWT is to be used for a conservative estimate of the benefit.

The transit toll for a 10,000 DWT general cargo vessel is $17,522 per transit (converted at 1 SDR = $1.3).

b) The number of transit vessels is as shown in Table 6-3-4 converted to standard transit vessels from the results of the forecast of transit demand in Part IV. In order to convert the actual number of transit vessels to that of standard vessels leaving at an interval of 10 min., the interval for each size of vessels is to be assumed as shown below. For the actual departing interval, Part VII should be referred.

Displacement	Time Internal
Non-tanker	(minutes)
0 – 30,000 NRT	8
– 60,000	10
60,000 –	12
Tanker	
0 – 60,000 DWT	12
– 150,000	16
– 250,000	16
– 300,000	16
300,000 –	16

Table 6-3-4 Forecast Number of Standard Ships (Base Case)

(ships/day)

Year	Real Ship	Standard Ship				
		Tanker	Bulk Carrier	General Cargo Ship	Container, LASH RO/RO, Others	Total
1980	68.3	15.60	6.97	29.16	10.62	62.35
1985	83.9	17.63	8.53	36.11	13.12	75.39
1990	103.3	20.58	10.11	44.98	16.97	92.64
1995	120.1	21.95	11.47	52.87	20.60	106.89
2000	139.6	22.21	13.12	62.63	25.02	122.98

c) The number of transit vessels for the computation of the increase in revenue is estimated by the method shown below:

$$\left(\begin{array}{l}\text{Transit capacity under}\\ \text{each plan}\end{array}\right) - \left(\begin{array}{l}\text{Transit capacity after}\\ \text{the First Stage Project}\end{array}\right) = \left(\begin{array}{l}\text{Number of transit vessels}\\ \text{for the computation of}\\ \text{the increase in revenue}\end{array}\right)$$

However, it will take some time for the number of transit vessels to reach the theoretical capacity under each phased plan. Such a period of time may be estimated from Fig. 6-3-13. Conversion, in monetary terms, of the effect of reduced hours is based on the principles given below:

a) As in the case of the computation of the increase in revenue, the projected size of vessels for the computation of the effect of reduced hours is to be a 10,000 DWT general cargo vessel. The number of transit vessels for computation is to be the the yearly total number of transit vessels. The cost for a 10,000 DWT vessel is US$6,480 per day.

b) The reduction in transit hours is to be the difference between the average waiting hours after the completion of the First Stage Project and those under each phased plan as shown in Table 6-3-1. However, in Plan 1-1, in order to allow southbound large-sized vessels to make transits, it is necessary for them to leave Port Said about four hours earlier, assuming that they require a transit time period of two hours (see Fig. 6-3-11). If these large-sized vessels are assumed to be between 275,000 DWT tankers and 120,000 DWT bulk carriers in size, the ship cost per day will be as shown below.

275,000 DWT tanker:	26,430 $/day
120,000 DWT bulk carrier:	19,080 $/day
Average:	19,255 $/day

In Plan 1-1, the additional time required for an average large-sized vessel to make a transit is to be regarded as a negative benefit. The number of transit vessels during the time period of two hours will be 7.5 vessels per day at an interval of 16 min.

c) As in the case of the reduction in waiting hours at the both ends of the Canal after the completion of whole doubling the Canal, the projected size of vessels for the computation of the effect of reduced hours is to be a 10,000 DWT general cargo vessel. The reduced hours at Port Said and Suez are to be, in average, 10 hours per ship respectively. The number of transit vessels and the cost for a 10,000 DWT vessel are the same as in (a) above. This benefit will be enjoyed only by Plan 5.

(3) Comparison

On the basis of the above costs and benefits, the cost-benefit ratio under each plan may be computed as shown in Table 6-3-5 for a computation period of 20 years after the completion of work. As these ratios do not include all costs generating benefits, it is not safe to regard them as absolute values; it is only to ascertain the difference among the phased plans.

As a result, Plan 0 shows the highest profitability while Plan 1 – Plan 5 show similar profitabilities between 1.3 and 1.8. As the unit cost of dredging is higher on the southern part of the canal compared with the northern part, the more to the south the plan is implemented, the lower the profitability. The high profitability under Plan 0 and the low rate under Plan 2 – Plan 5 are partly due to this factor.

As regards Plan 5, as the demand is not expected to reach the capacity even after a period of 20 years computation, the benefit of two-lane canal is not fully enjoyed.

Judging from the above, there is no marked difference in profitability as far as Plans 1~3 are concerned. High profitability may be obtained in Plan 0, while Plans 4 and 5 seem to be somewhat low in profitability due to the characteristics of the area to be dredged.

Of Plan 1, Plan 1-3 shows slightly lower profitability compared with Plans 1-1 and 1-2 despite higher costs; this is due to the expected effect of reduced transit hours. The same applies to Plan 2. In Plans 3 and 4, however, as the effect of reduced hours is equal to that of Plan 1-3, the profitability falls in proportion to the rise in the dredging cost.

Table 6-3-5 Economic Evaluation Indexes

	Cost (10^6 US$)	Benefit (10^6 US$)				Cost-Benefit Ratio (Discount Rate : 15%)
		Total	Additional Revenue	Time Saving: Transit Time Saving	Time Saving: Early Depature Loss	
Plan 0	84.5	1,074.7	1,232.8	△ 158.1	–	3.48
Plan 1-1	244.3	2,107.4	2,842.4	△ 559.4	△ 175.6	1.81
Plan 1-2	387.9	2,802.9	2,740.3	62.6	--	1.69
Plan 1-3	614.7	3,787.9	2,995.7	792.2	–	1.29
Plan 2	441.7	3,401.4	3,225.7	175.7	–	1.66
Plan 3	671.6	4,887.5	4,024.2	863.3	–	1.50
Plan 4	767.2	5,940.6	5,007.8	932.8	–	1.37
Plan 5	1,144.2	9,646.3	8,444.1	1,202.2	–	1.32

The results of the evaluation of cost-benefit ratios may be outlined as below.

a) Plan 0 offers high profitability with a short work period.

b) In Plan 1, Plan 1-1 requires the minimum construction cost resulting in high profitability, but produces no effect of reduced hours. In view of the same capacity shown by the other Plan 1s, it may be concluded that Plan 1-2 or Plan 1-3 is probably desirable judging from the international role to be played by the Canal.

c) In Plans 2~5, as the unit cost of dredging rises towards the southern part of the canal, the profitability falls in the order of Plans 2, 3, 4 and 5. Accordingly, these plans have to be implemented at an appropriate time to correspond the increasing demand.

d) It may thus be considered from the above that Plan 0 may be implemented first to meet the present demand. This must be followed immediately by the Plan 1-2 to obtain increased capacity and reduced hours. Plan 2~5 may afterwards be implemented according to the increase in demand.

3-3-2 Study of the transit capacity

This section is intended to ascertain when the capacity reaches the saturation point under each phased plan, in the light of the results of the demand forecast. Capacity saturation here is examined by converted standard vessels. Though the saturation point for the canal is to be studied in the next Part with a simulation model, overall results are similar to those obtained here.

(1) Transit demand in the standard vessel

Table 6-3-6 shows the figures converted to the number of standard vessels for every five years from 1980 based on the results of the transit demand forecast made in Part IV. Conversion to the number of standard vessels is made based on the transit time interval of each vessel used under (2), 3-3-1. Fig. 6-3-13 shows the movement of the number of standard vessels for the period from 1980 to 2000 under each case with respect to demand.

Table 6-3-6 Daily Number of Standard Ships

	Real Ship			Standard Ship		
	Low Case	Base Case	High Case	Low Case	Base case	High Case
1977		53.9			49.2*	
78		58.2			53.2*	
80	66.2	68.2	70.3	59.3	62.4	63.8
85	76.5	83.9	91.8	68.6	75.4	82.3
90	92.5	103.3	118.1	83.0	92.6	105.0
95	107.9	120.1	141.5	96.3	106.9	124.6
2000	125.3	139.6	170.8	110.9	123.0	148.5

Note: 1) The number of standard ships in 1977 and 1978 was estimated referring to the relation between real ships and standard ships in 1980.

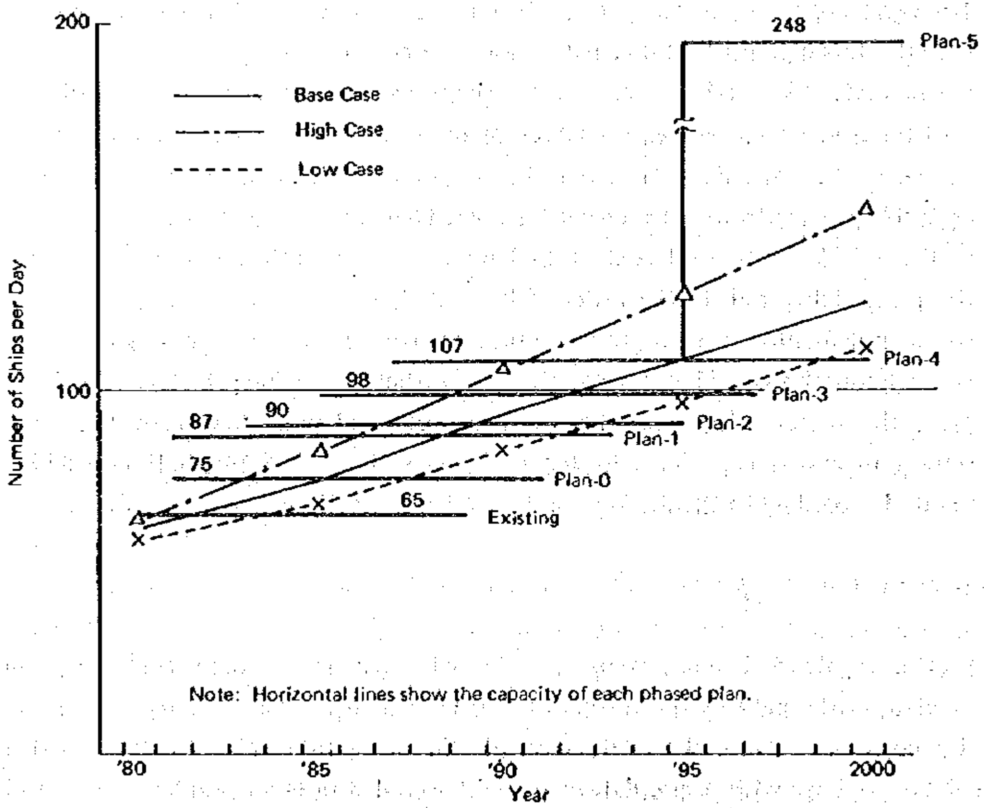


Fig. 6-3-13 (1) Demand and Transit Capacity (1)

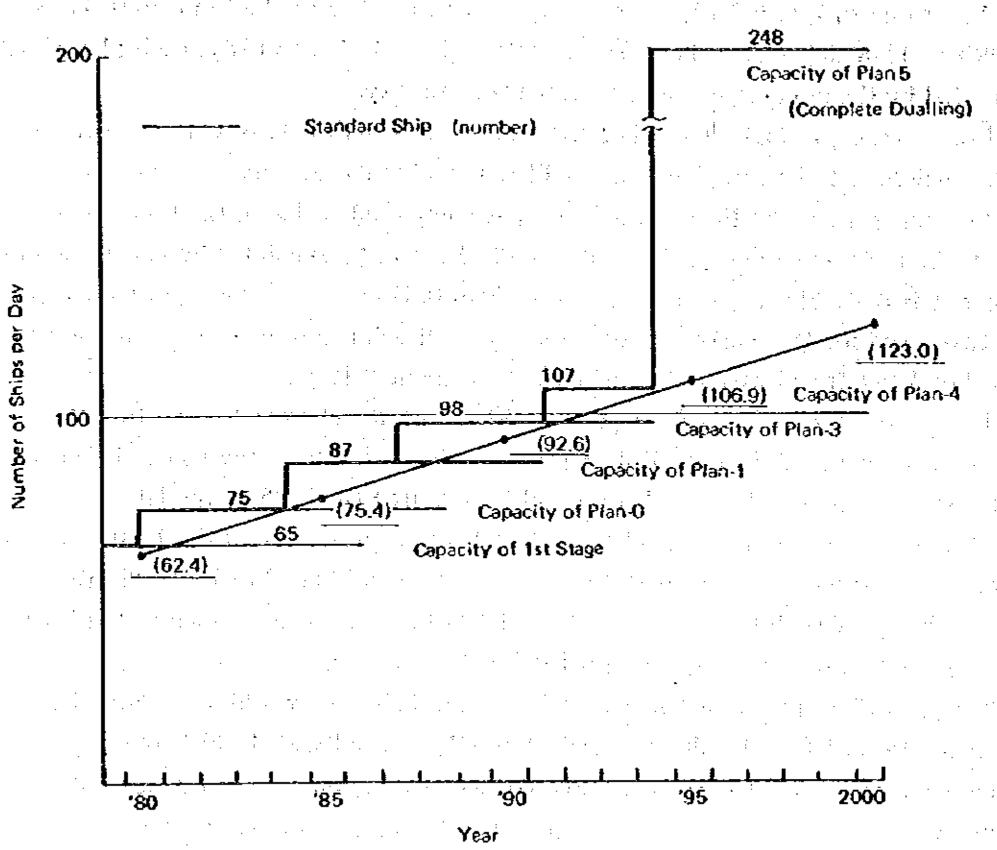


Fig. 6-3-13 (2) Demand and Transit Capacity (2)
(Base Case of Demand)

(2) Canal saturation point

A study is to be made as to how long the capacity under each phased plan may be able to meet the transit demand.

Table 6-3-2 shows the theoretical daily capacity under each phased plan. It may be noted that the transit time interval is not realistic and that the passing of convoys may not be performed without a second of loss as shown by the diagram; loss of time will therefore be inevitable. Though the loss of time is to be studied in Part VII, 5% of the navigable time is allocated here to time loss.

As the transit demand shown in Fig. 6-3-13 is the average number of transits per day, the actual number of transits varies from day to day. As a result of the examination of the actual data in Part VII, this distribution seems to be governed by Poisson's distribution as in the general case of ship arrivals at harbours.

Accordingly, assuming that transit vessels show the Poisson's distribution and there is to be waiting at Port Said and Suez of 1~2 days per month, the transit capacity under each plan corresponding to the daily average number of vessels may be obtained as shown in Table 6-3-7 (this transit capacity is called the daily average capacity whereas the capacity computed initially is called the theoretical daily capacity).

The saturation point under each plan may be obtained by combining the daily average capacity of Table 6-3-7 and Fig. 6-3-13, and the results are as shown in Table 6-3-8.

According to Fig. 6-3-14, the capacity may be reached in 1984 in Plan 0, 1988 in Plan 1, 1990 in Plan 2, 1992 in Plan 3 and 1995 in Plan 4. Accordingly, each plan should be superseded by the next stage before reaching the capacity.

For instance, though Plan 5 is estimated to reach its capacity considerably later than 2000, it will have to be completed before Plan 4 reaches its capacity.

Further, even if the First Stage Project is completed in 1980, the Canal will reach its capacity in 1981 and the capacity will actually have to be expanded by that time. For that purpose it is desirable to give precedence to Plan 0. However, as it is expected to require at least two years for the works and the capacity itself will reach the saturation point towards the end of 1984, it will have to be superseded by the next stage.

During the Phase I which projects 1990 as the target year for the First Phase Plan, expansion to two lanes in Plan 3 must proceed. Further, during the Phase II, expansion of the entire canal to two lanes in Plan 5 will be required by 1995 at the latest. Even in the case of a larger increase in demand (High Case), the capacity under the First Stage Project will reach its saturation point in 1980, Plan 1 in 1986 and Plan 3 in 1988, all prior to 1990. The possibility of High Case in demand until 1990 is forecast to be high and at least Plan 3 will be required during the Phase I with 1990 as the target year.

On the other hand, in the case of stagnancy in the world economy (Low Case), implementation of Plan 1 will be sufficient for the Phase I with 1990 as the target year. As the demand in the Base Case is a fairly conservative estimate, such a possibility will be extremely low.

Table 6-3-7 Daily Average Transit Capacity

	Daily Average Transit Capacity (ships/day)	Theoretical daily Capacity (ships/day)
Existing (After 1st Stage)	65	84
Plan 0	75	94
Plan 1	87	108
Plan 2	90	112
Plan 3	98	120
Plan 4	107	128
Plan 5	248	288

Table 6-3-8 Saturation Years of the Canal Capacity

	Base Case	Reference	
		High Case	Low Case
Existing	1981	1980	1983
Plan 0	1984	1983	1987
Plan 1	1988	1986	1992
Plan 2	1990	1987	1993
Plan 3	1992	1988	1996
Plan 4	1995	1990	1999
Plan 5	after 2000	after 2000	after 2000

3-4 Overall Evaluation

On the basis of the results of the above study this section is intended to select a two-lane development plan to be implemented as the Phase I under the Second Stage Project with 1990 as the target year. At the same time, the stepwise plan is to be studied under the Phase I plan.

3-4-1 First Phase Plan under the Second Stage Project

According to the study of profitability under each plan in 3-3-1, it seems the most suitable to expand the capacity of the Canal gradually by doubling the Canal in accordance with the increase of demand. In order to confirm this finding, profitability in the case of investment in Plan 5 for the two-lane expansion of the entire Canal according to the demand may be studied.

The investment schedule may be prepared as shown Fig. 6-3-14 so that before the demand reaches the capacity the investment for the next stage will have been completed. It must be noted that this investment schedule is an ideal one adjusted to the demand and the actual investment plan will be different as various conditions other than the demand must be considered.

As regards benefit, assuming a project life of 20 years after the commencement of operation on each section, an increase in revenue and the effect of reduced hours on each section are to be adopted as benefit. Computation of benefit is to be made on the same principles as those in 3-3-2. The cost-benefit ratio computed from these cost and benefit is 1.66, higher than the figure of Plan 5 obtained in 3-3-1.

It is thus economical to make investments according to the demand. Accordingly, if the target year is 1990, the two-lane expansion should be carried out partially according to the demand of 1990 for the time being rather than planning the expansion of the entirely doubled Canal from the beginning as in the Second Stage Project. According to this approach, the Second Stage Project may be divided into stepwise plans below (see Fig. 6-3-15):

Step	Dualling Section	'81	'82	'83	'84	'85	'86	'87	'88	'89	'90	'91	'92	'93	'94	'95
1	Km 61 ~ 95	construction period								→ opening						
2	Km 16 ~ 51					construction period						→ opening				
	Km 122 ~ 135					construction period						→ opening				
3	Km 135 ~ 144.5								construction period						→ opening	
4	Km 144.5 ~ 162.4											construction period				→ opening
Transit Capacity Secured (Standard Ships)		65	65	65	65	87	87	87	98	98	98	107	107	107	248	248
Transit Demand (Standard Ships)		65	68	70	73	75.4	79	82	85	89	92.6	95	98	101	104	106.9

Fig. 6-3-14 Tentative Investment Schedule of Plan-5

	Doubled Section	Construction Section for Doubling
First Phase Plan (Phase I)	Km 0 – 135	Km 16–92, Km 61–95, Km 122–135
Second Phase Plan (Phase II)	Km 0 – 162	Km 0–16, Km 135–162 Port Said Approach Channel Suez Entrance Channel

As for the First Phase Plan, as seen in Fig. 6-3-14 with respect to the future increase in transit demand, the capacity under the First Phase Plan (98 ships/day of daily average capacity) will be sufficient until 1992, when the demand will be 98 standard ships per day. For the demand after 1993, unless a part of the Second Stage Plan (Plan 4) is completed by that time the daily average capacity will reach its saturation point.

In view of the above, Plan 3, which is projected to expand the section Km 0-135 to two lanes is to be adopted for the First Phase Plan under the Second Stage Project with 1990 as the target year.

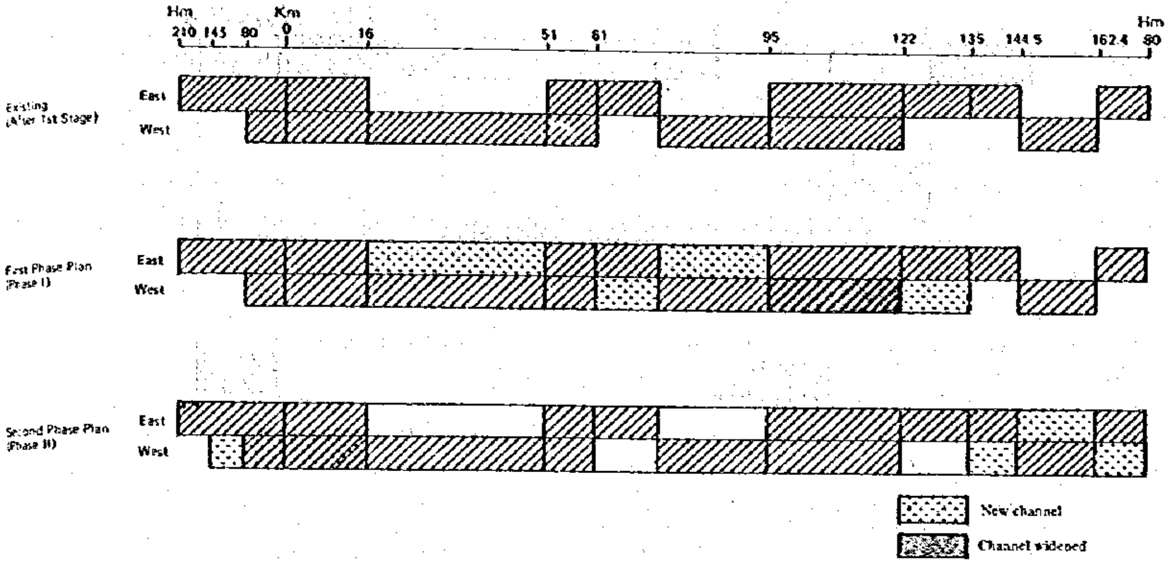


Fig. 6-3-15 Proposed Program of Doubling the Canal

3-4-2 Stepwise Plans under the First Phase Plan

Even after the completion of the First Stage Project, the Canal capacity is expected to reach saturation in the early 1980's. Accordingly, it is desirable from the viewpoint of meeting the demand to proceed with partial two-lane expansion in the first half of the 1980's.

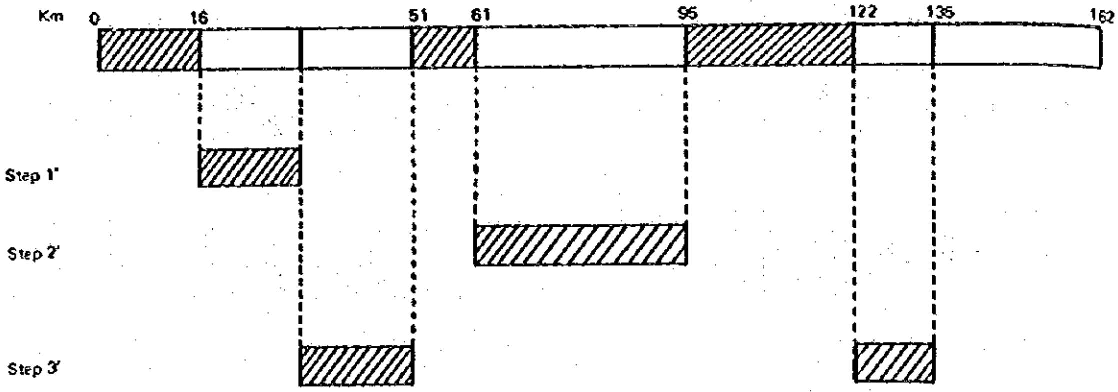
If the First Phase Plan is implemented in parts, the capacity will gradually increase. As shown in Fig. 6-3-16, the demand may gradually increase by expanding the section Km 16–32.5 in Step 1', section Km 61–95 in Step 2' and sections Km 32.5–51 and Km 122–135 in Step 3'.

However, as the construction under the Step 1' requires at least two years, even if the Step 1' is completed in 1983, the capacity will reach its saturation point in just over a year's time. Further, for partial operation under the Step 1', the single-lane and two-lane sections will have to be connected over a few km on both sides of the point Km 32.5. Unless this section is divided into east and west channels with a jetty after the two-lane expansion of the single-lane section, hydraulic interference may occur when transit vessels pass each other, thus affecting navigation. As the cost of the jetty cannot be ignored, it does not seem to be advantageous to give precedence to the Step 1'. Accordingly, it is desirable to implement the Step 2' as soon as possible to be followed by the Step 1' and Step 3' implemented in parallel.

Fig. 6-3-17 shows the two steps of Canal opening under the First Phase Plan. The time of opening of each step in relation to the demand may be outlined as below:

Step 1: As the capacity under the First Stage Project will reach its saturation point in 1981, the earliest possible completion of construction is desirable.

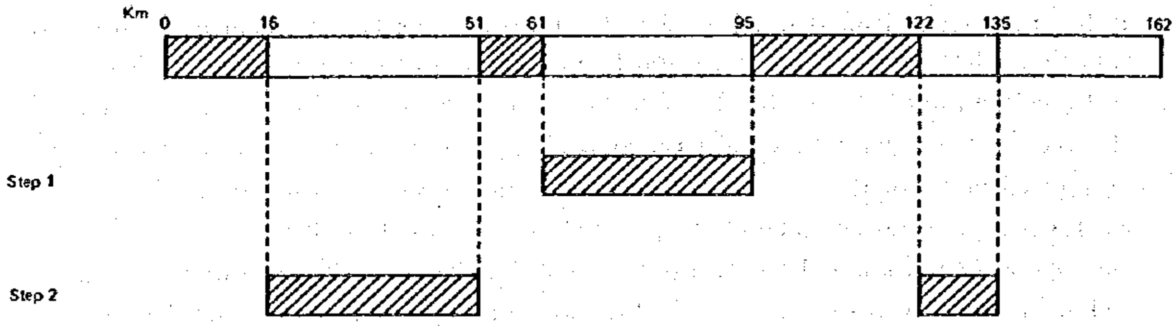
Step 2: As the capacity under the Step 1 will reach its saturation point in 1988, it is desirable to complete the construction in 1987 at the latest.



The characters of each step are shown as follows.

	Volume (10^4 m^3)		Construction Cost (10^6 \$)	Theoretical Transit Capacity (ships/day)	Average Transit Capacity (ships/day)
	Dredging	Excavation			
Step 1'	67.9	14.0	84.5	94	75
Step 2'	141.8	99.0	387.9	108	87
Step 3'	119.6	34.0	199.2	120	98

Fig. 6-3-16 Stepwise Opening Program



The characters of each step are shown as follows.

	Volume (10^6 m^3)		Construction Cost (10^6 \$)	Theoretical Transit Capacity (ships/day)	Average Transit Capacity (ships/day)
	Dredging	Excavation			
Step 1	141.8	99.0	387.9	108	87
Step 2	187.5	48.0	283.7	120	98

Fig. 6-3-17 Improved Stepwise Opening Program

Though the work schedule of the Step 1 will be described in detail in Part IX: Implementation Plan, completion is not expected before the end of 1984, and considerable ship waiting is expected at Port Said and Suez between 1982 and 1984. Chapter VII: Transit Scheme and Transit Capacity may be referred to in regards to the waiting condition.

In order to reduce waiting during the period from 1982 to 1984, a tentative transit method can be used by forming a small convoy between the current southbound convoy 1 and 2 (the small convoy to be called S 2-1 convoy and the current convoy S 2-2) which proceeds to Suez after awaiting the northbound convoy on the west channel of the Timsah Lake. The traffic diagram of this tentative method is as shown in Fig. 6-3-18. The diagram is based on the assumption that the number of waiting vessels at the Timsah Lake is 6; the capacity is therefore larger than the current one by 6.

The above stepwise plans for the First Phase Plan show the conditions to be satisfied in relation to the demand and the actual implementation plan is to be studied in Part IX including various conditions other than the demand.

Existing (After 1st Stage)

Cycle 24 hrs 4 convoys a day

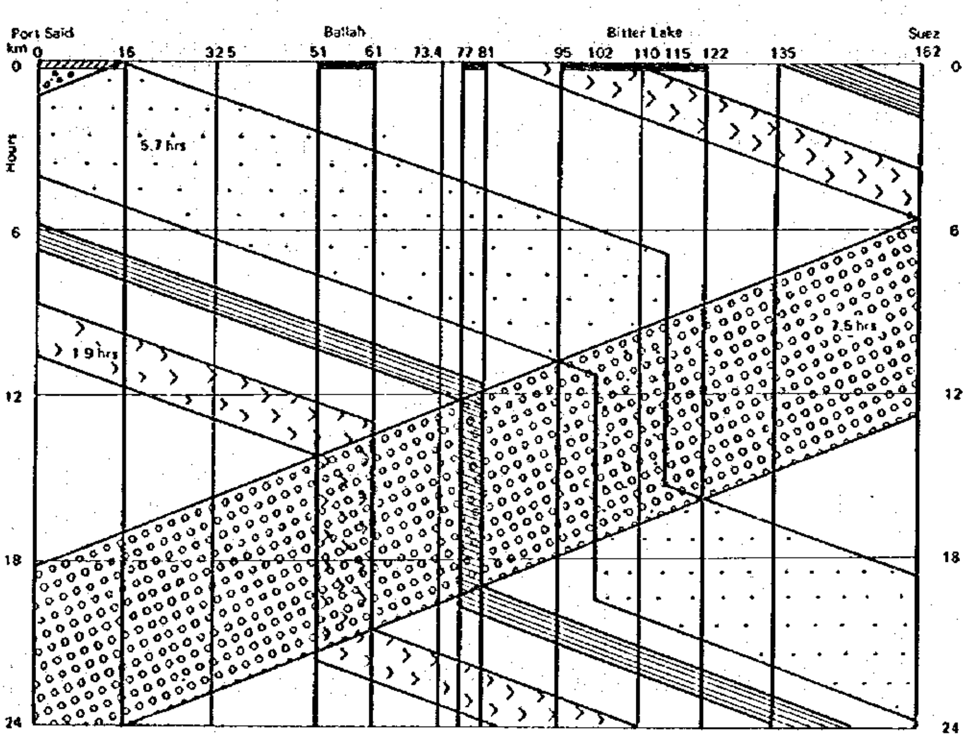
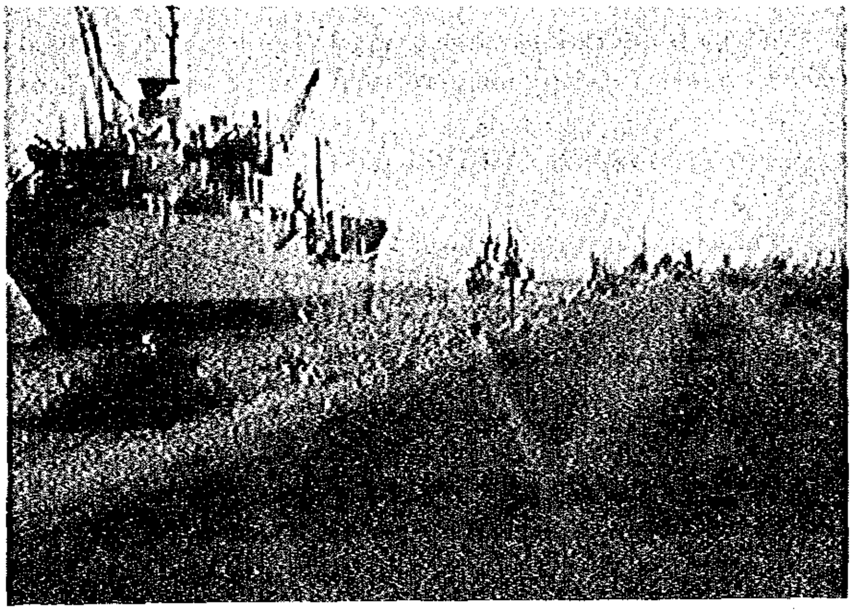


Fig. 6-3-18 Traffic Diagram (12)



Ⅶ. Transit Scheme and Transit Capacity

PART VII TRANSIT SCHEME AND TRANSIT CAPACITY

1. Present Transit System

The Suez Canal, including the two ports of Port Said and Suez, is under the control of the Suez Canal Authority which controls over the transits through the Canal based on its Rules of Navigation.

The Canal is now almost at the final stage of the First Stage Development Project. The channel depth has been increased to 19.5 m and its navigable width at a water depth of 11 m has been increased to about 160 m. Yet, it is a narrow and restricted channel compared with ordinary shipping lanes.

For this reason, one-way traffic is being maintained for the Canal except for the sections of bypasses and the Great Bitter Lake.

All the transit ships must book their transits at least five days prior to their scheduled date of transit. In addition, each ship must notify the SCA by radio at least 48 hours before her scheduled time of arrival, and give her name, nationality, tonnage, owner, etc.

1-1 Convoy Transit System

A convoy is formed of ships having arrived at either entrance to the Canal, Port Said or Suez, by a certain time.

(1) Each 24 hour period, two convoys are formed of ships proceeding south from the Mediterranean Sea to the Red Sea and one convoy is formed of ships proceeding north from the Red Sea to the Mediterranean Sea.

a) South-bound Convoy No.1 (S1) is composed in the following order of priority:
   - a. Warships
   - b. Passenger ships
   - c. Ordinary ships located in the harbor
   - d. VLCCs and other large ships proceeding directly from anchorage outside the harbor

   Slow speed ships are assigned to the rear end of a convoy.

b) Convoy No. 2 (S2) is composed of:
   - a. Ships of less than 15,000 tons; Ships with a maximum draft of 9.14 m (30 ft); Ships with maximum width of 30 m (98 ft).
   - b. Slow speed ships meeting the above requirements
   - c. Ships with deficiencies

   The number of these ships must not exceed 19, which is the number of ships that can be accommodated in the Ballah West Channel.

(2) A north-bound convoy proceeding from the Red Sea to the Mediterranean Sea is divided into two groups.

The first group is composed in the following order of priority:

a. Warships
b. Passenger ships
c. Car carriers
d. RO/RO
e. Container ships
f. LASH vessels
g. Ordinary vessels with draft of 35 ft or over
h. Ordinary vessels with average draft of 33 ft or over
i. Tankers

The second group is composed of ordinary ships other than the above.

(3) Transit of convoys

South-bound Convoy No. 1 leaves Port Said during 02:00 – 06:00 (in the designated order at ship-to-ship intervals of 5 – 20 minutes according to ship size and cargo type) enters the canal and starts navigating toward the Great Bitter Lake. It stands at the South Anchorage of the Great Bitter Lake, to wait for the northbound convoy to pass, and resumes its southward navigation for Suez as soon as the last ship of the northbound convoy enters the Great Bitter Lake.

Convoy No. 2 leaves Port Said during 09:30 – 11:30 seven hours 30 minutes after the departure of the Convoy No.1, and moors in the Ballah Bypass, to wait for the north-bound convoy to pass, and resumes navigation toward Suez after the last ship of the north-bound convoy passes the Km 60 point.

The first group (tanker group) of the north-bound convoy leaves Port Suez from 06:00 for the Great Bitter Lake and the second group leaves Suez at an interval of 30 – 60 minutes after the departure of the tanker group, and completes its entry into the canal at 10:00.

This convoy is reorganized at the North Anchorage of the Great Bitter Lake, bringing tankers with dangerous cargoes to the front to be followed by ordinary ships. Ships bound for Port Said are now at the rear.

1-2 Canal Traffic Control and Regulations

To ensure the efficient operation of the canal and the safety of navigation, SCA maintains traffic control with respect to the organization of convoys and the monitoring of ship movements. For this purpose, it has a central navigation control office and a radio station at Ismailia, a harbor control office each at Port Said and Port of Suez and 11 signal stations along the west bank of the canal; these facilities maintain close contact with pilots belonging to the SCA.

In the Canal and at Port Said, vessels of 500 Suez tons or over (at Suez, 300 Suez Tons or over) are subject to compulsory pilotage. Furthermore, ships must observe radio instructions given directly from the control office.

The speed for transit through the canal is usually limited to 7.5 kt (14 km/h); 7 kt (13 km/h) is the limit for north-bound loaded tankers.

The order of ships in a convoy is designated by the control office. Certain time (distance) is set for the interval between ships according to the size of ships and the type of cargoes.

In the channel, overtaking, crossing and anchoring are prohibited.

2. Transit Scheme after the First Stage Development Project

2-1 SCA-proposed transit scheme after the First Stage Project

Under the First Stage Project, the Port Said Bypass (16 km), the Deversoir Bypass (6 km), the Kabret Bypass and the Great Bitter Lake anchorage have been improved to increase the transit capacity of the Canal and improve safety of navigation.

As a principle, the existing transit system is reportedly continued after the completion of the First Stage Project, but it will be partially changed as follows:

1) A north-bound convoy goes non-stop, proceeding from the Great Bitter Lake to the Mediterranean Sea via the newly created Deversoir and Port Said Bypasses.

2) Large ships with drafts of 38 ft or over in the south-bound convoy (S1) proceed directly from the waiting anchorage outside the breakwater to the Great Bitter Lake via the Port Said Bypass.

3) With the completion of the First Stage Project, the Canal becomes available for the transit of ships up to around 150,000 DWT with full load and up to around 300,000 DWT in ballast.

4) The interval between large tankers will be 25 minutes

2-2 Introduction of navigation control system after completion of the First Stage Development Project

The Suez Canal Authority starts to install the Suez Canal Vessel Traffic Management System (SCVTMS) in early 1980 to ensure further safety in Canal navigation in preparation for the transit of VLCCs after the widening of the canal. This system will be put into operation by the end of 1981. It is composed of:

1) Monitoring radar system
2) LORAN C ship positioning system
3) Computerized information processing system
4) Communications system

A carry-on receiver transmitter (CORT) is brought on board each transit ship simultaneously with the boarding of a pilot outside the harbor. The CORT receives electric waves from the LORAN C station and automatically transmits information, including the code specifying the ship to the ground station (control center), whereupon the signals are analyzed and processed by the computer at the control center. The present position and speed of the ship and necessary ship data are indicated on the display at the control office.

Further, monitoring by the controller is added by an automatic early warning device incorporated in this display, to warn the controller of speeding of ships, their deviation from the fairway, the abnormal time intervals between ships, and slowdowns.

3. Present Conditions of Canal Transit

3-1 Distribution of ships arrival

3-1-1 Frequency

The daily transit frequency of ships using this Canal was analyzed from the transit records of 1978. Histograms, Fig. 7-3-1 and 7-3-2, were made by ship type, because this classification was used in the records.

In the histogram for tankers, the probability density of Poisson's distribution overlaid by dotted lines shows much the same trend as the actual distribution.

Accordingly, the transit frequency of tankers is considered to be governed by the Poisson's distribution without calibration.

In a similar attempt, the transit frequency of non-tankers also generally corresponds with the probability density of the Poisson's distribution.

Thus, it is concluded that the arrival pattern of transit ships at Port Said and Suez is governed by the Poisson's distribution.

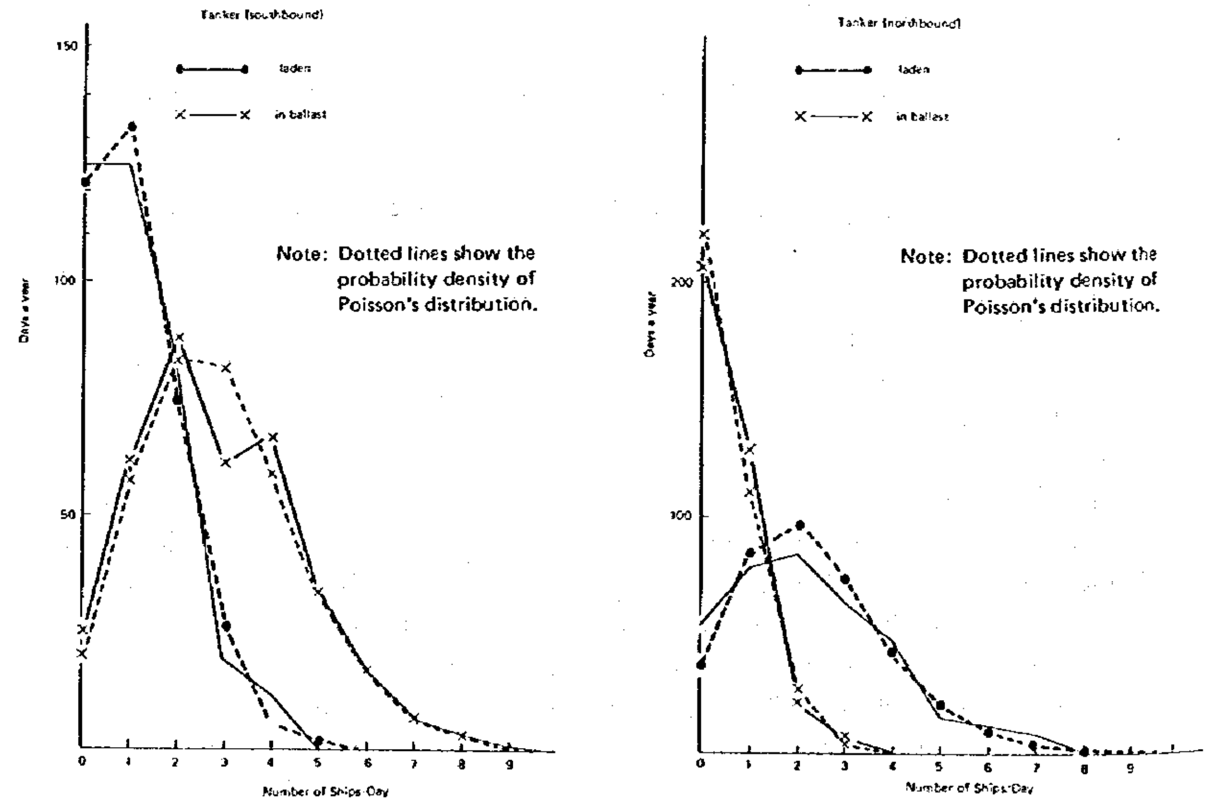


Fig. 7-3-1 Histogram of Transited Tankers in 1978

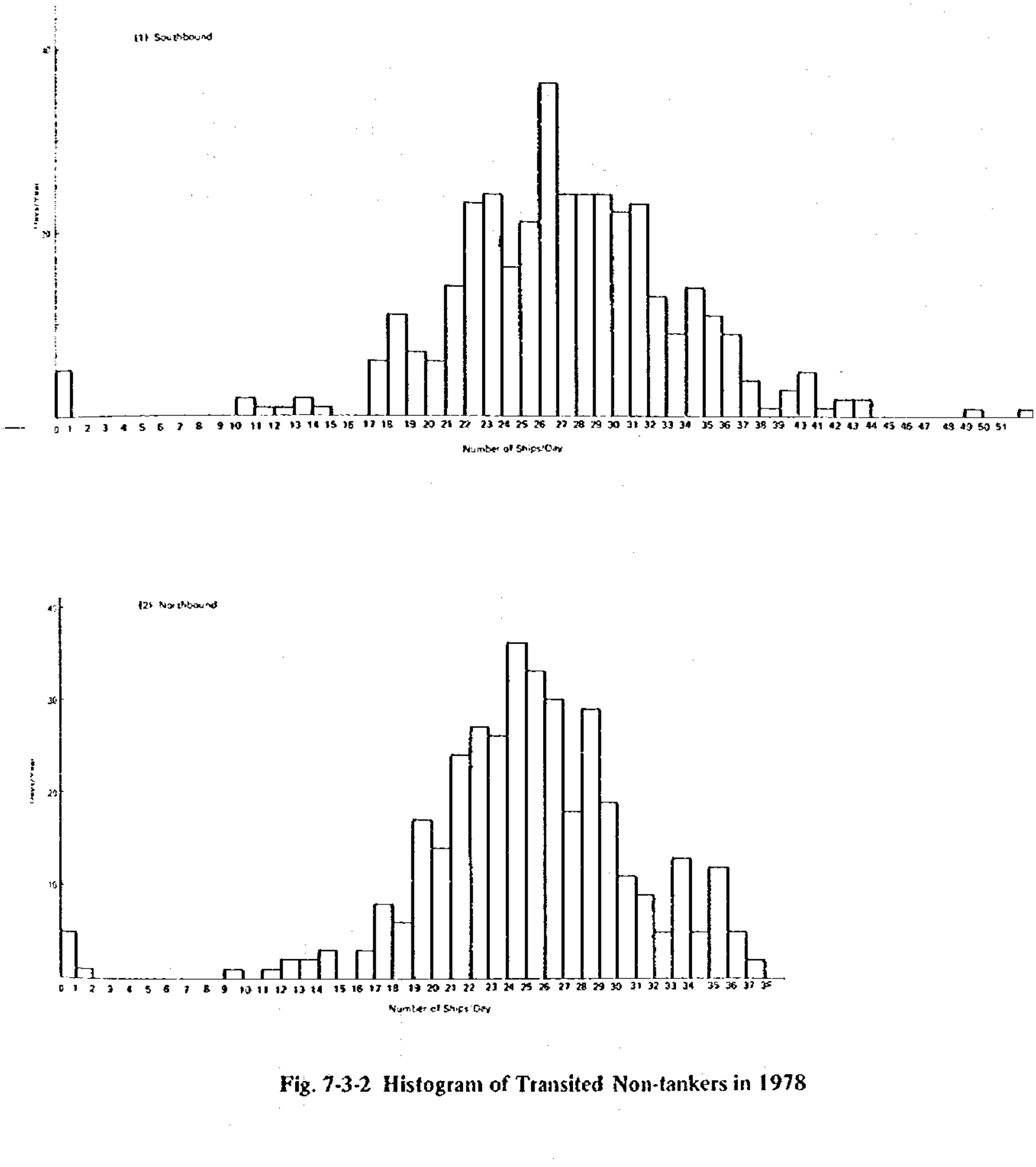


Fig. 7-3-2 Histogram of Transited Non-tankers in 1978

3-1-2 Arrival frequency by time

Fig. 7-3-3 shows the distribution of ships arrival by time, which was prepared from transit records of the two weeks from September 1 to 15, 1979. These data cover about 800 ships and were obtained by computer processing from the time of arrival of each ship in the open sea and the time of her entry into the canal as recorded by the control rooms at Port Said and Suez.

According to this figure, the number of arriving northbound ships decreases for several hours prior to the departure of the convoy but remains to be generally even during other period with almost no peak. As for southbound ships, there is a slight peak in the early afternoon but this peak is not remarkable. So, it is considered that the distribution of ships arrival at Port Said and Suez is more or less uniform and ships arrive at random.

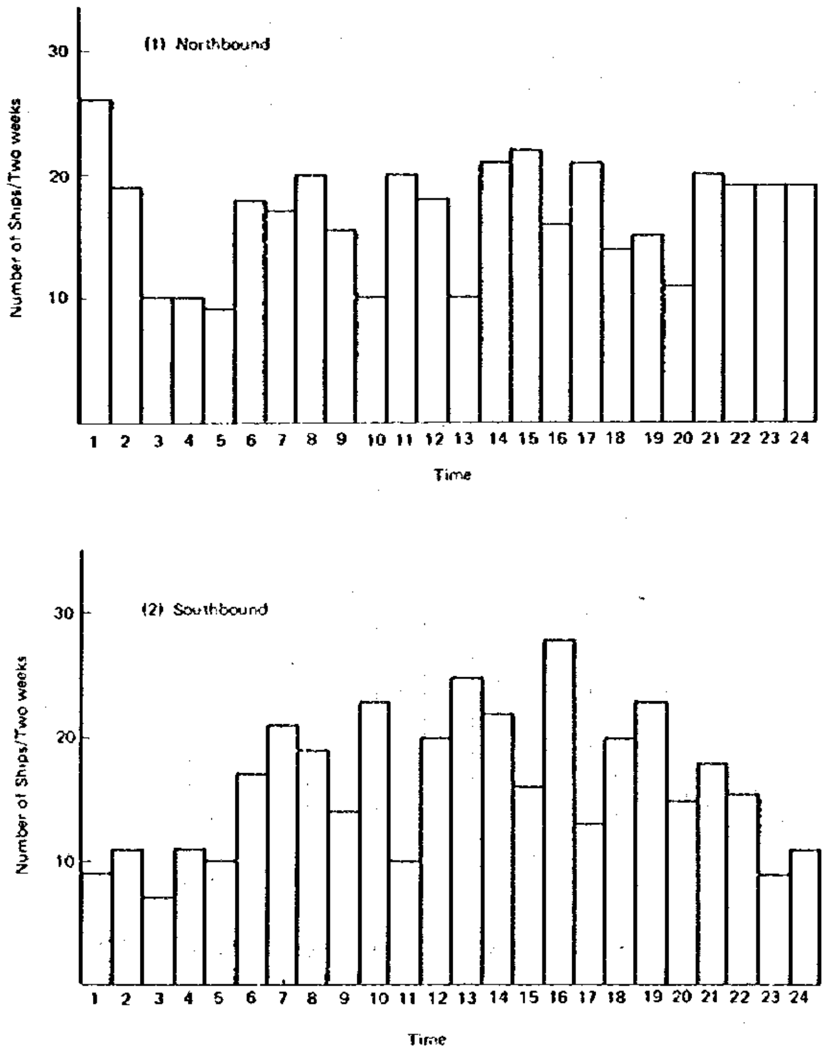


Fig. 7-3-3 Distribution of Ship Arrival Time

3-2 Ship waiting

Fig. 7-3-4 shows the waiting of ships at Port Said and Suez during the two weeks of September 1 to 15, 1979.

According to this figure, the waiting time of northbound ships – here, ships which waited for more than 30 hours are excluded on the assumption that they had to wait due to some special reasons – is distributed generally evenly and there is almost no peak around the average waiting time. On the other hand, the waiting time of southbound ships is distributed in a trapezoid shape showing primarily 6 – 20 hours of waiting time.

The average waiting time of northbound ships is 21.8 hours and that of southbound ships is 17.1 hours, but, if instances of waiting for more than 30 hours are excluded, the average waiting time of northbound and southbound ships is 18.6 hours and 15.0 hours respectively. Considering that ships must arrive at least four hours prior to their departure for transit procedures, the actual waiting time is 14.6 hours and 11.0 hours respectively, the average for the two directions being 12.8 hours.

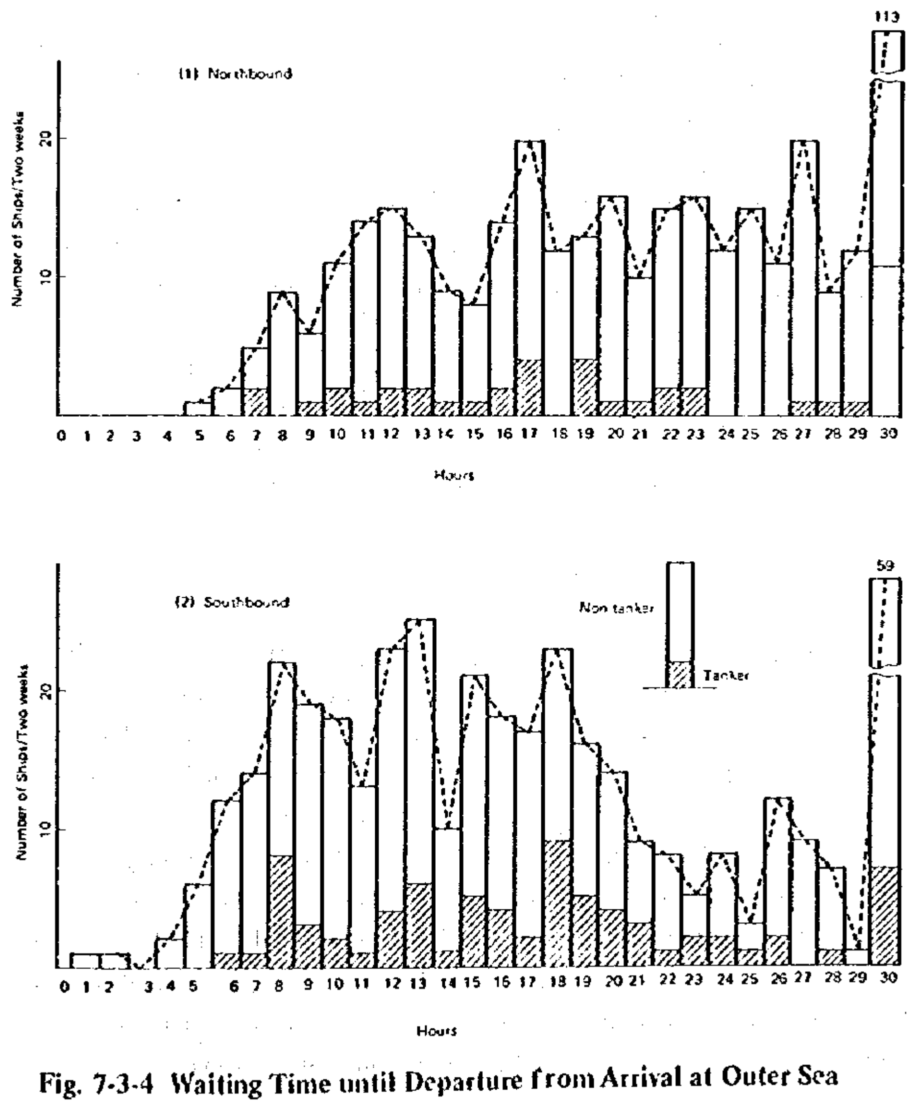


Fig. 7-3-4 Waiting Time until Departure from Arrival at Outer Sea

3-3 Time intervals between ships

Time intervals between ships were analyzed for transit ships from the records during the two weeks from September 1 to 15, 1979. Table 7-3-1 shows the records on average time intervals between ships, by ship type and size. These records were obtained by computer processing from the time records of ships entering the Canal from the waiting anchorage or directly from the open sea at Suez and Port Said. Therefore, the results are concerned with the time intervals between ships entering the Canal and these intervals are not necessarily maintained throughout Canal transit; that is these intervals may be shortened or extended during the transit of ships throughout the Canal. These results show that general cargo ships leave at intervals of about eight minutes while container ships (including RO/ROs, LASHes, car carriers and other ships) of up to 10,000 NRT leave at intervals of eight minutes or less and those in excess of 10,000 NRT leave at intervals of more than 10 minutes. Intervals between bulk carriers are also more than 10 minutes because they are mostly large. Intervals between tankers of up to 30,000 DWT are 11 minutes and those between tankers in excess of 30,000 DWT are 12 minutes in the case of laden ships and 16 minutes in the case of ships in ballast.

Fig. 7-3-5 shows the distribution of time intervals by ship type and by direction of transit. Characteristically, there is a considerable fluctuation around the average value in the case of northbound ships, but, in the case of southbound ships, most time intervals concentrate on certain values. It is considered that northbound transit is affected by tide and time intervals differ between head and following tidal currents.

As for ship type, time intervals of tankers vary around 11 minutes in northbound transit while those of southbound tankers concentrate on 10 minutes, 15 minutes and 20 minutes. Time intervals of northbound bulk carriers vary around seven minutes and 10 minutes while those of southbound bulk carriers concentrate on 10 minutes. Time intervals of northbound general cargo ships vary around six minutes while those of southbound general cargo ships concentrate on 10 minutes. Time intervals of northbound container ships vary with relative concentration on five minutes, eight minutes and 10 minutes while those of southbound container ships relatively concentrate on six minutes, 15 minutes and 20 minutes, in addition to 10 minutes.

3-4 Time loss due to waiting for opposite convoys

When convoys proceeding in both directions pass each other at either end of the canal or at waiting areas in the Canal, they cannot pass the Canal so without time loss, as indicated in the diagram. One convoy cannot, for psychological and other reasons, navigate at the given speed until it confirms that the other convoy has passed the meeting point; such measures as a speed adjustment and a stop at the time of meeting seem to be unavoidable.

Analyzing the actual time loss is extremely difficult even from actual diagrams. Here, time lost by southbound convoys at the Ballah Bypass was calculated as in Table 7-3-2 from the speed change of each ship and her mooring time, using the diagrams of 10 days in December 1977. The loss of an average 10 minutes occurred at the time of departure for speed adjustment, etc. Also, extra time of about 13 minutes was required at the time of stop at the Ballah Bypass but all this cannot be regarded as lost time since it appears to include time for mooring.

Table 7-3-1 Record of Transit Intervals between Ships

(minutes)

	Tanker				Bulk Carrier				General Cargo Ship				Container Ship & Others			
	N/B	S/B	Both	For Simulation	N/B	S/B	Both	For Simulation	N/B	S/B	Both	For Simulation	N/B	S/B	Both	For Simulation
SCNT:																
– 5,000					–	–	–		8.25	10.18	9.22	9	6.88	9.74	8.00	8
– 10,000					9.78	10.00	9.88	10	8.33	10.25	9.13	9	7.80	9.29	8.27	8
– 15,000					11.00	10.35	10.56	11	8.94	10.78	9.71	9	10.31	11.14	10.52	10
– 20,000					11.60	11.63	11.62	12	7.00	10.00	7.75	9	9.00	9.67	9.33	10
– 25,000					12.20	18.33	14.50	12	8.00	–	8.00	9	9.56	12.20	10.50	10
– 30,000					9.00	11.67	11.00	12				12	12.25	12.17	12.20	12
– 40,000								12				12	12.60	11.25	12.00	12
– 50,000								12				12	15.00	18.33	16.29	16
– 60,000								12				12				16
– 70,000								12				12				16
– 80,000								12				12				16
80,000 –								12				12				16
			For Simulation N/B	For Simulation S/B												
DWT:																
0 – 30,000	11.00	11.31	12	12												
– 60,000	12.36	15.89														
150,000	–	20.21	25	20												
250,000	–		–	20												
300,000	–	–	–	25												
300,000 –		–	–	25												

Note: 1) The record of time interval was obtained by processing the actual transit record from Sep. 1 to 15, 1979.
2) The values in 'For Simulation' are used for the simulation test in Chapter 4-3.

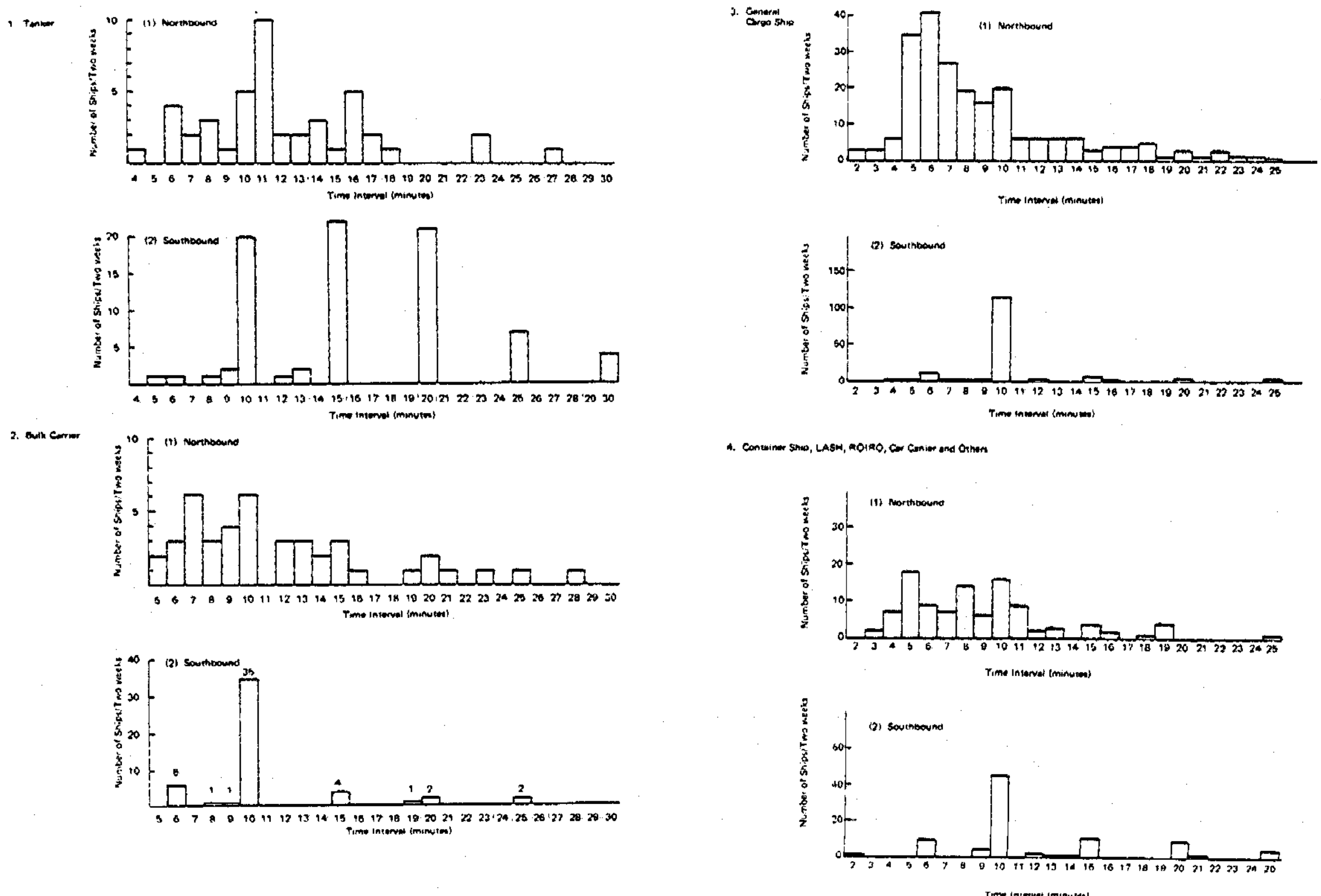


Fig. 7-3-5 Distribution of Time Interval by Ship Type

Table 7-3-2 Loss Time at Ballah Bypass

	Date	Number of Ships	Average Time Lost
		ships	minutes
Loss Time at Departure	Dec. 22, 1977	9	10
	Dec. 24, 1977	9	5
	Dec. 25, 1977	14	13
	Average		9.3 ≑ 10
Loss Time at Stop	Dec. 22, 1977	9	13.8
	Dec. 24, 1977	9	10.9
	Dec. 25, 1977	14	15.6
	Dec. 27, 1977	6	6.7
	Average		12.6 ≑ 13

3-5 Ship speed

Table 7-3-3 shows the results of the transit speeds obtained from the records of a week from December 21 to 27, 1977. Since all the diagrams did not indicate ship types, it was impossible to show the results by ship type.

In this table, the transit speeds are approximately 16 km/h and 17 km/h, respectively, which greatly exceed the speeds prescribed in the Rules of Navigation(*). It is probably possible for small ships to transit at a high speed because of their sufficient area ratio (Ar), but it is feared that the return current and ship wave induced by navigation at a high speed may affect bank slopes and revetments. The transit capacity of the Canal does not increase through the speed-up of a convoy if it includes a single ship transiting at a low speed. Therefore, the prescribed speeds should be observed strictly.

(*) In a week's records, a southbound 72,015 G/T transit tanker navigated the section 0-104 km at 18.3 km/h. Some northbound container ships and RO/ROs seem to navigate the section Km 162-122 at more than 20 km/h. High speeds to a certain extent may be inevitable in this section because of the effect of tidal current, but, even so, this speed greatly exceeds the prescribed limit in the Rules of Navigation.

Table 7-3-3 Actual Average Navigation Speed

(km/h)

	Southbound				Northbound			
	No. of Ships	km 0–104	km 104–162	Total	No. of Ships	km 162–104	km 104–0	Total
21, Dec. 1977	23	15.5	15.8	15.7	27	15.8	17.9	16.9
22	34	15.6	17.7	16.6	32	15.9	18.6	17.3
23	35	15.5	17.1	16.3	34	16.5	18.0	17.3
24	35	15.6	17.5	16.6	34	15.6	18.0	16.8
25	29	13.7	16.7	15.2	17	15.2	18.4	16.8
26	31	15.4	16.2	15.8	28	16.0	18.0	17.0
27	37	15.3	16.1	15.7	24	15.9	17.0	16.5
Average	32	15.2	16.7	16.0	28	15.8	18.0	16.9

4. Transit Simulation Test

4-1 Purpose

In Part VI the Second Stage Development Project, the transit capacity in standard ships (ships leaving at an interval of 10 minutes) was studied for reference necessary for the comparison of the phased plans.

In reality, ships with different size transit the Canal at time intervals varying with the ship type and size instead of the fixed interval of 10 minutes.

Therefore, a study of the saturation of the Canal capacity should be made by a more realistic method. In order to examine what factors influence the Canal capacity, several simulation tests were made on the capacity using a simulation model.

The purpose of these simulation tests is as follows:

- Effect of increasing convoy cycle time on transit capacity
- Effect of allowing two-way traffit to small ships on transit capacity
- Effect of increasing transit speed on capacity
- Effect of decreasing time intervals between ships on transit capacity
- Situation of ship waiting
- Handling of waiting ships after a temporary closure of the Canal
- Saturation of Canal capacity after the completion of the First Stage Project
- Saturation of Canal capacity under the phased plans of the Second Stage Project

4-2 Flow chart of forecasting and structure of the model

The outline of the simulation model is shown in Fig. 7-4-1.

Principal data to be put into the model are such transit conditions as speed, time interval between ships and tolerance time, conditions for forming convoys, the daily number of transit ships and the topographic conditions which were conditions of the canal such as doubled sections. The transit ships forecast in Part IV for each year are to arrive at Port Said and Suez for a continuous 40 days, according to a Poisson's distribution.

Accordingly, the number of transit ships in Base Case and High Case of demand for the period until the year 2000 is predicted. Therefore, it is possible to put it out for any year in the period of 1980 – 2000 in accordance with each stage of development of the Canal.

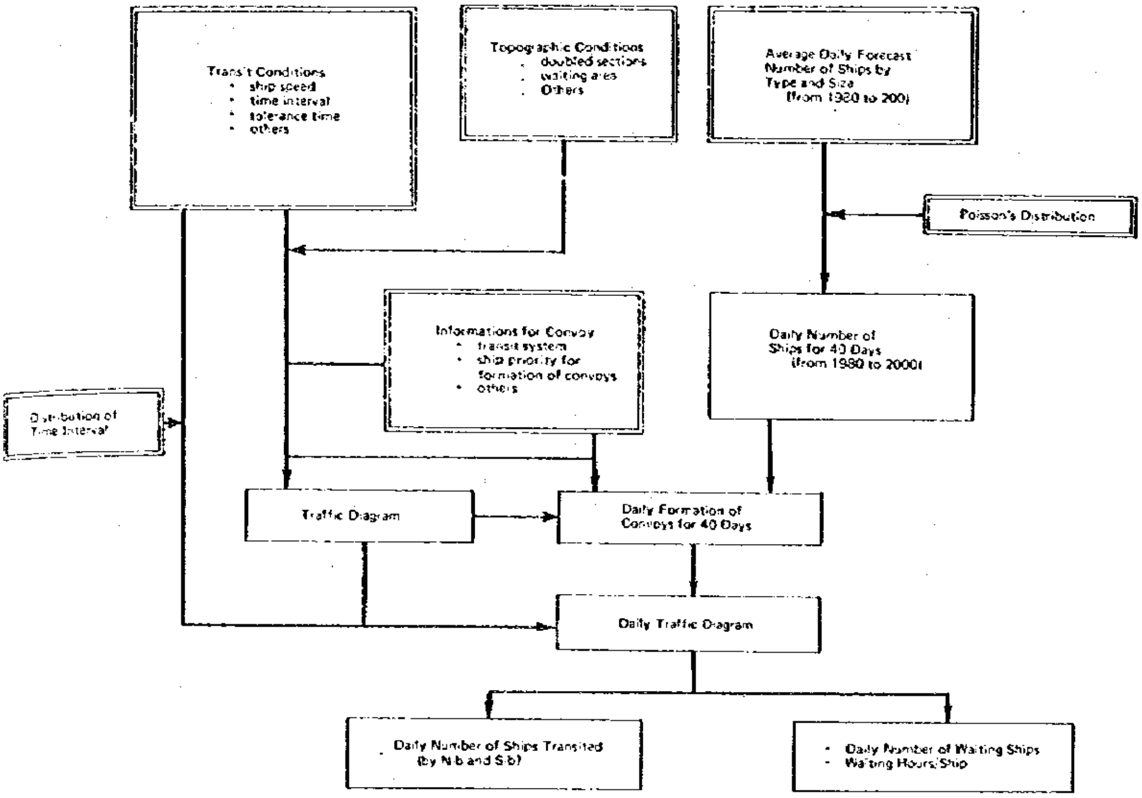


Fig. 7-4-1 Outline of Transit Simulation Model

4-3 Simulation

4-3-1 Simulation cases

This simulation concerns the effect of capacity on the analysis, and will examine how various factors of transit influence the transit capacity saturation under the First and Second Stage Projects. The test also concerns the effect of employing a provisional transit system, aimed to promptly cope with ships that have to wait at Port Said and Suez if the Canal is temporarily closed.

(1) Capacity effect analysis

The saturation of the Canal is examined with the following factors likely to influence capacity:

- Transit cycle time
- Transit scheme allowing two-way traffic to small ships
- Ship speed
- Time intervals between ships

Influencial Factor	Computing Case	Development Stage
1. Cycle Time	1) 24 hr-cycle 2) 36 hr-cycle	Existing (After 1st Stage) "
2. Different Transit System to allow two-way traffic to small ships	allowable ship size less than 5,000 NRT	Existing (24 hr-cycle)
3. Ship Speed	1) 13 km: laden tanker 14 km: Other ships 2) 14 km: laden tanker 15 km: Other ships	Existing (24 hr-cycle) "
4. Time Interval between Ships	1) improved actual interval 2) actual interval 3) short interval 4) long interval	Existing (24 hr-cycle) " " "

(2) Capacity saturation analysis

The Canal capacity saturation by standard ships at each stage of development of the Canal studied in Part VI is to be reviewed by simulation tests. The cases to be computed are as follows:

Development Stage	Case of Demand	Transit System		Remarks
		No. of Convoys	Cycle Time	
1) Existing	Base Case High Case	N-b : 1 S-b : 2	24 hrs	
2) 2nd Stage Project Plan 1–2	Base Case High Case	N-b : 1 S-b : 2	24 hrs	
Plan 3	Base Case High Case	N-b : 1 S-b : 1	24 hrs	
Plan 4	Base Case High Case	N-b : 1 S-b : 1	24 hrs	

Note: N-b : Northbound S-b: Southbound

(3) Measures to cope with congestion

A measure against the closure of the Canal for several days due to an accident or inclement weather is to be tested. The study includes a case where the Canal is closed for several days in 1981 under the present conditions of the Canal. Details of the case computed are as follows:

Development Stage	Duration of Canal Closure	Year	Cycle Time
	days		hrs
Existing	3	1981	24, 36
	7	1981	" "

4-3-2 Input data

(1) Number of transit ships

Using the results of demand forecast in Part IV (daily number of transit ships by year, ship type and size), the transit ships are to arrive at Suez and Port Said for a continuous 40 days according to the Poisson's distribution. It is assumed from the results of analysis in Chapter 3 that ships will arrive continuously for 24 hours without fluctuation.

The results of transit forecast are put into files after performing the above-mentioned processing, prior to computation with respect to the Base Case and High Case of demand.

(2) Transit conditions

1) Ship speed

In the standard case, 13 km/h for tankers fully laden and 14 km/h for others as prescribed in the Rules of Navigations were used as ship speed. As for speed to be used in studying transit capacity in the case of speed-up, 14 km/h and 15 km/h, each with an increase of 1 km/h compared to the present prescribed speed, were adopted.

2) Time intervals between ships

Below are the cases where time intervals between ships were existing, shortened or extended to analyse the effect of these intervals on transit capacity.

Time Interval

	Actual Case (improved)	Short Interval Case	Long Interval Case	
	minutes	minutes	minutes	
Non-Tanker				
NRT				
0 – 30,000	8	6	8	
30,000 – 60,000	10	8	10	
60,000 or greater	12	10	12	
	laden and in ballast	laden and in ballast	laden	in ballast
Tanker				
DWT				
0 – 60,000	12	10	12	12
60,000 – 150,000	16	16	20	25
150,000 – 250,000	16	16	20	25
250,000 – 300,000	16	16	25	25
300,000 or greater	16	16	25	25

Values in the "For Simulation" column of Table 7-3-1 are employed in the existing case under the present conditions. In this case, the distribution in Fig. 7-4-2 showing the present variations is applied to time intervals. Fig. 7-4-2 was prepared from the time intervals between ships shown in Fig. 7-3-5.

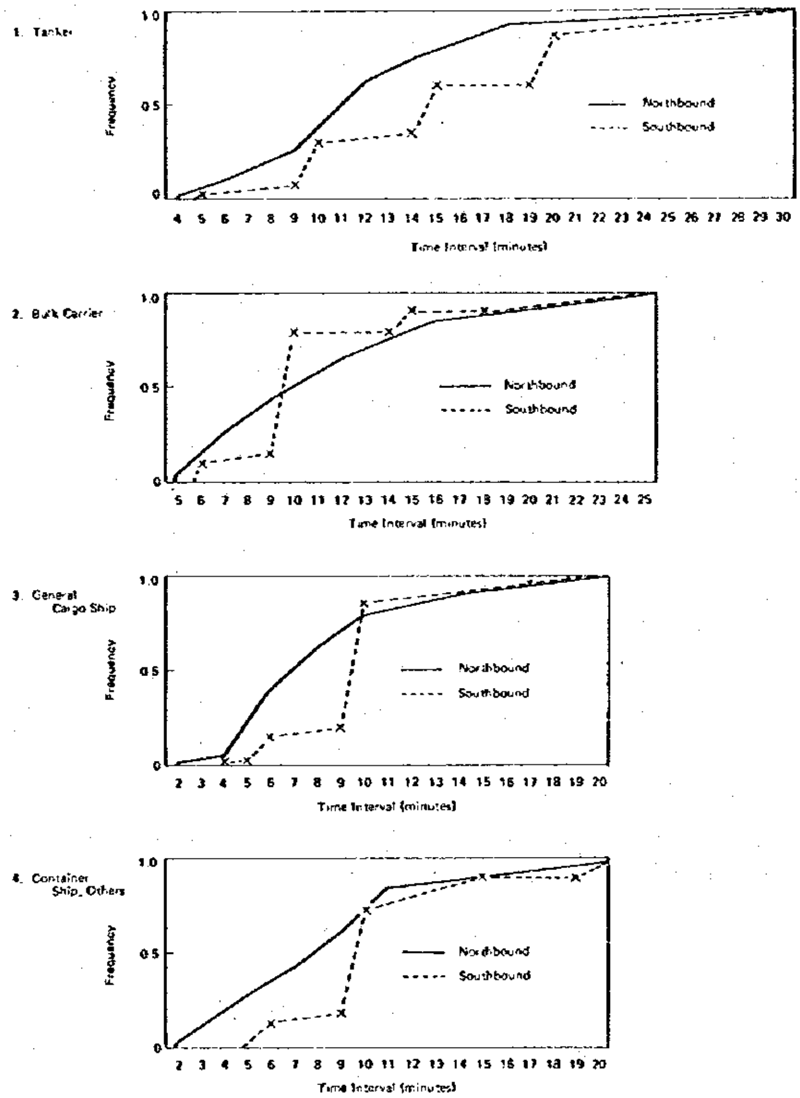


Fig. 7-4-2 Accumulated Distribution Pattern of Time Interval

3) Tolerance time

The tolerance time is considered to be small when southbound convoys wait in the Great Bitter Lake and the Ballah Bypass, as under the present system, but the elasticity of time adjustment will be lacking when a non-stop convoy also is operated in southbound transit. Accordingly, 15 minutes were subtracted for each convoy under the present system as anticipated tolerance time and 20 minutes in the case of non-stop convoys operated in both southbound and northbound transit.

(3) Waiting area in the Canal

Under the present system after the completion of the First Stage Project, southbound convoys wait in the Ballah Bypass and the Great Bitter Lake, as in the past. As for the number of ships that can be accommodated in each waiting area, 19 ships are accommodated in the Ballah Bypass, 33 ships in the south anchorage of the Great Bitter Lake and 20 ships in the north anchorage of the Lake. But in the case of a 36-hour-cycle time, this accommodation is insufficient; so, 36 and 60 ships are to be accommodated in the north anchorage and the south anchorage, respectively, on the assumption that the number of accommodated ships can be increased by mooring with two anchors and by overlapping parts of the swinging area. Nineteen ships are accommodated in the Ballah Bypass as in the past.

(4) Transit system

For transit, a system in accordance with the stage of development of the Canal is to be applied. In the case of the existing Canal, the system adopted comprises one northbound convoy (non-stop) and two southbound convoys. At each step of development under the Second Stage Project, non-stop convoys will be in principle, applied for northbound transit, but for southbound transit, non-stop convoys will be adopted only when there is time for doing so. Transit systems under Phase I (Plan 1-2 and Plan 3), for which simulation tests were conducted, are shown in Fig. 6-3-5 and Fig. 6-3-8 in Part VI. The navigation time is apportioned 50% for southbound and 50% for northbound transit because the number of ships is nearly the same between the two directions. Since the number of southbound ships is slightly larger than that of northbound ships, ship waiting will occur earlier on the Port Said side.

(5) Priority in forming convoys

As described in Chapter 1: Present Transit System of Part VII, there is a certain order by ship type and size in forming convoys at Port Said and Suez. The present priority in forming convoys is used in this simulation. However, a new priority system, incorporating the continued use of the present priority in so far as possible is set for the Second Stage Project and the case where a new transit system, such as the allowing two-way traffic to small ships, is employed. For reference, the priority under the present transit system employing one northbound convoy and two southbound convoys, and the priority under the passing-in-opposite-directions system, are shown in Table 7-4-1. For a traffic diagram under the passing-in-opposite-direction system, see Fig. 7-4-3.

(6) Others

The latest time of arriving ships to be incorporated into convoys is four hours prior to the departure of each convoy.

Table 7-4-1 Ship Priority for Convoy Formation

Ship Type	Tanker					Bulk Carrier											
Displacement	a	b	c	d	e	a	b	c	d	e	f	g	h	i	j	k	l
Existing																	
N-1 convoy	2	2	2	2	2	5	5	5	5	5	5	5	5	5	5	5	5
S-1 convoy	1	2	2	2	2	4	3	3	3	2	2	2	2	2	2	2	2
S-2 convoy	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Transit system to allow small ships in opposite directions																	
N-1 convoy	2	2	2	2	2	6	5	5	5	5	5	5	5	5	5	5	5
N-2 convoy	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
S-1 convoy	1	2	2	2	2	7	6	6	6	2	2	2	2	2	2	2	2
S-2 convoy	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
S-3 convoy	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0

Ship Type	General Cargo Ship												Container Ship											
Displacement	a	b	c	d	e	f	g	h	i	j	k	l	a	b	c	d	e	f	g	h	i	j	k	l
Existing																								
N-1 convoy	5	5	5	4	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	1	1
S-1 convoy	4	4	3	3	3	3	2	2	2	2	2	2	4	4	4	3	3	2	2	2	2	2	2	2
S-2 convoy	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
Transit system to allow small ships in opposite directions																								
N-1 convoy	6	5	4	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	1	1
N-2 convoy	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S-1 convoy	7	6	5	5	5	5	3	3	3	3	3	3	7	6	6	4	4	2	2	2	2	2	2	2
S-2 convoy	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
S-3 convoy	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0

Note: 1) The displacement of ships is shown as follows:

Tanker: a : 0 ~ 60,000 DWT b : ~ 150,000 DWT c : ~ 250,000 DWT d : ~ 300,000 DWT e . 300,000 DWT ~

Bulk Carrier:
General Cargo Ship:
Container Ship: } a : ~ 5,000 NRT b : ~ 10,000 NRT c : ~15,000 NRT d : ~ 20,000 NRT e : ~ 25,000 NRT f : ~ 30,000 NRT g : ~ 40,000 NRT h : ~ 50,000 NRT i : ~ 60,000 NRT j : ~ 70,000 NRT k : ~ 80,000 NRT 1 : 80,000 NRT ~

2) Each figure shows ships priority to be incorporated into a fixed convoy.

Different Transit System Allowing Small Ships to Pass in Opposite Directions

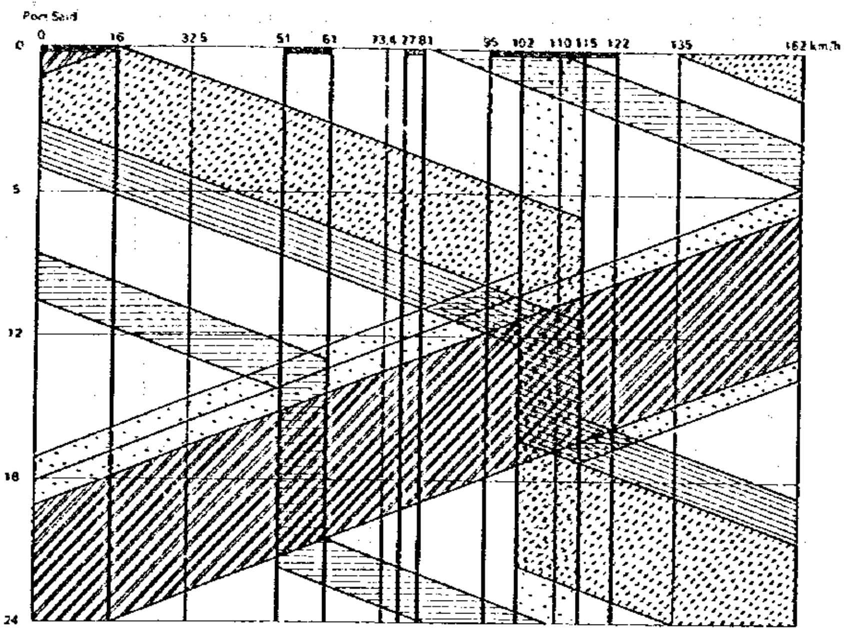


Fig. 7-4-3 Traffic Diagram (13)

4-4 Results and consideration

4-4-1 Capacity effect analysis

(1) Cycle time

The state of waiting was investigated with respect to a 36-hour-cycle transit in addition to the existing 24-hour-cycle transit system. In this study, the existing convoy system of one northbound convoy and two southbound convoys was employed, but the maximum time duration of two hours was assigned to the S-2 convoy. The navigable time duration under each transit system and the number of standard ships available for transit are as follows:

	Navigable Time Duration per cycle	Navigable Time Duration per Day	Navigable Number of Ships per Day
24 hr-cycle	14.16 hrs/cycle	14.16 hrs/day	84
36 hr-cycle	26.28	17.52	105

The transit capacity under the 36-hour-cycle system will increase 25% from the level under the present transit system, and thus is equivalent to the level for Plan 1 of the phased development plans.

It can be forecast from the results of the simulation test that, if the 36-hour-cycle transit system is adopted, until 1986 the transit demand can be met without expanding the canal. However, waiting time will increase because of the long time cycle, if queuing begins to occur. The merits and demerits of the 36-hour-cycle system are described in 5-3-2 in this Part (See Fig. 7-4-4).

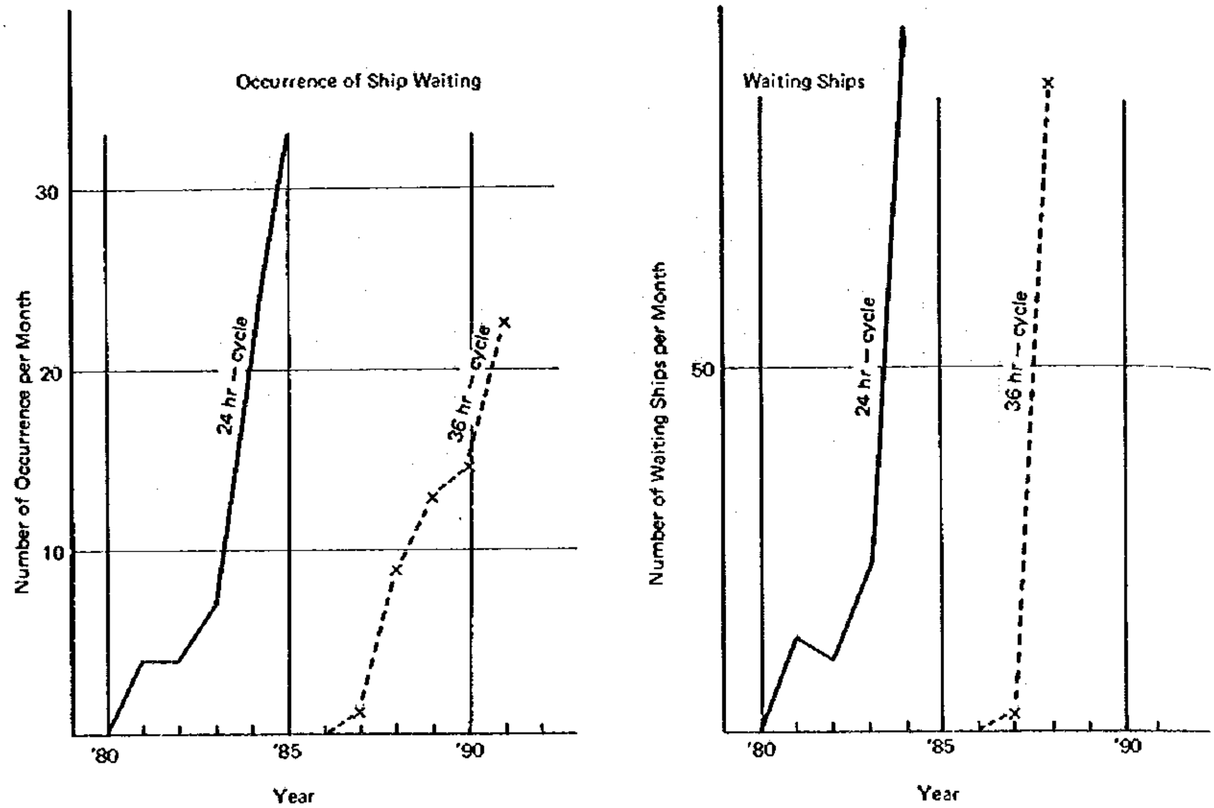


Fig. 7-4-4 Effect of 36 Hour-Cycle Transit System

(2) System of allowing two-way traffic to small ships

Allowing ships, even small ones, to pass each other in opposite directions in the limited space of the canal is undesirable for the safety of navigation. Therefore, two-way traffic system should be limited to small ships as much as possible; tankers laden with dangerous cargoes and container ships which cannot easily adjust their speed should be excluded. Ships with a width up to, say, 1/9 of the width of the canal may be allowed to pass each other, but, in this study, passing in opposite directions is limited to ships not exceeding 5,000 NRT. The width of a 5,000-NRT ship is approximately 1/11 of the width of the canal.

The traffic diagram for the passing two-way traffic system is shown in Fig. 7-4-3. The occurrence of ship waiting can be postponed for about two years, compared with the present system, by employing the two way traffic system (see Fig. 7-4-5). If this improvement is all that can be expected of this system, which involves danger of navigation, some other method should be used to increase transit capacity.

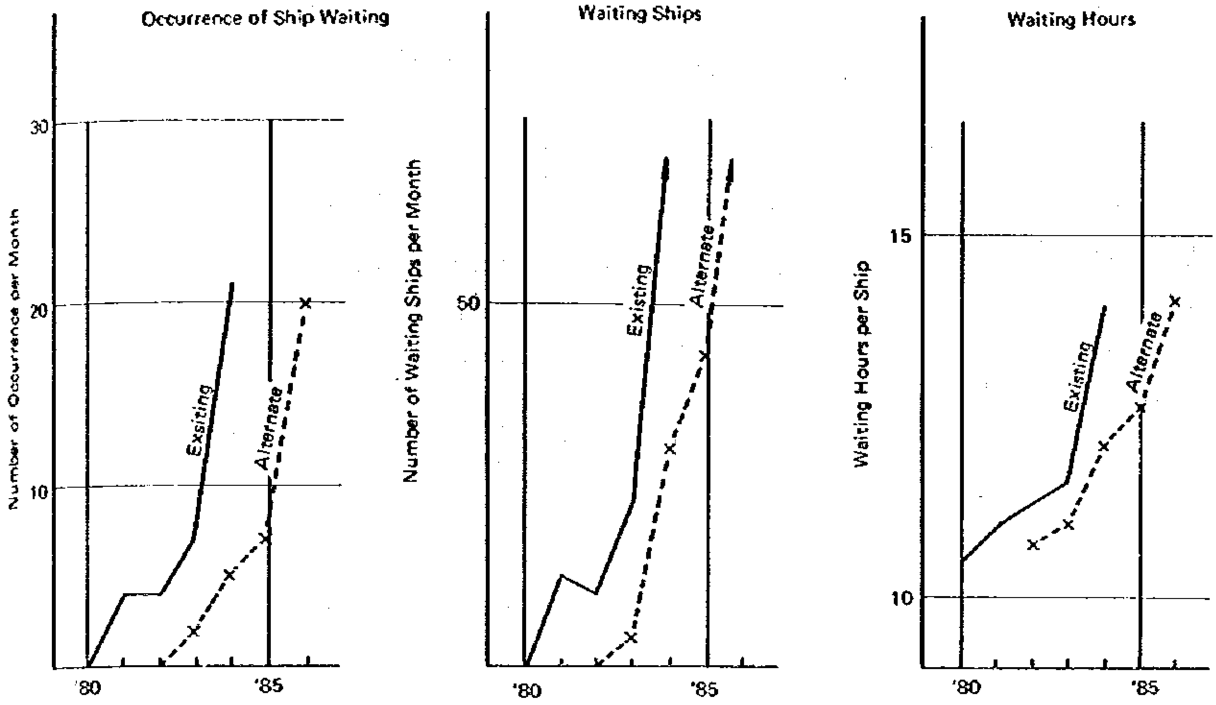


Fig. 7-4-5 Effect of Alternate Transit System (Allowing two-way traffic to small ships)

(3) Ship speed

A study of how transit capacity will be influenced by a 1-km/h increase in the speed of tankers and other ships was made. The navigable time duration and the number of standard ships available for transit in this case are as follows:

	Navigable Time Duration	Navigable Number of Ships
Existing Speed	14.16 hrs/day	84 ships
Speed Increased	15.40	92

Thus the transit capacity can be increased by 10%, thereby equivalent to a capacity level for Plan 0 under the phased development plans.

The results of the simulation test seem to indicate that the time of capacity saturation may be postponed for about a year, compared with operation at the present ship speed. (See Fig. 7-4-6)

However, problems are involved, particularly for VLCCs, due to the navigational resistance of tankers. For this reason and because of no drastic capacity increase such a speed-up, cannot be a realistic scheme.

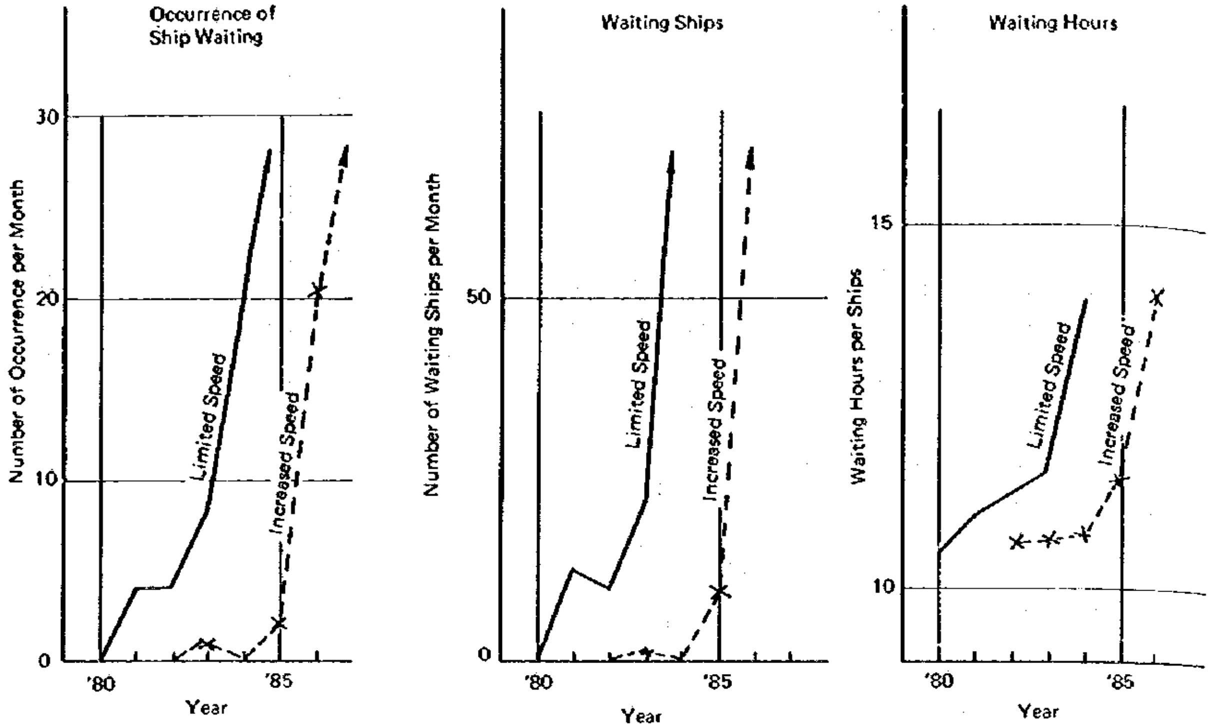


Fig. 7-4-6 Effect of Increasing Ship Speed by 1 km/h.

(4) Time interval between ships

The transit situation prevailling after the First Stage Project was studied by using the actual time intervals from the records of September 1979, shown in Table 7-3-1. In this study, actual variations in time intervals were given by the distribution shown in Fig. 7-4-2.

The results of the simulation test indicate that, if the present time intervals are maintained, waiting may occur immediately after the completion of the First Stage Project. The results of a forecast on ship waiting in 1981 are as follows:

	Number of Ship Queues per month	Number of Waiting Ships per month	Waiting Hours hours/ship
Actual Interval	36	603	17.36
Improved Interval	0	0	11.01

Such waiting, should it occur, would have been considerable in the Canal at present, but it does not seem that there is much waiting at present. In light of time intervals available from accurate records, it may be considered that a decrease of transit capacity is actually being avoided by increasing ship speed.

Anyway, if the present time intervals between ships are used hereafter in operating the Canal a capacity shortage will occur soon in the Canal after the First Stage Project. Hence, it is necessary to accurately control time intervals by adopting the SCVTMS.

From the study of the effect on transit capacity by the shortening or extending of time intervals (for details of the shortening, see "Input Data" in 4-3-2), if time intervals are shortened, the number of transit ships increases (see Fig. 7-4-7). Thus, after the completion of the First Stage Project, the occurrence of ship waiting can be put off considerably. Meanwhile, the extension of time intervals for tankers will result in the decrease of transit capacity and will soon cause saturation in the Canal, after the First Stage Project. In the tentative computation, a duration of 20–25 minutes was used as the time interval between VLCCs. Since the SCA apparently considers 25 minutes as the time interval between VLCCs, the result of the computation should be seriously taken into consideration for operating the Canal after the First Stage Project.

As seen above, time intervals between ships have a direct impact on canal capacity. Accordingly, this problem must be carefully studied in view of the safety of navigation. The time interval between VLCCs is discussed in detail in 5-3.

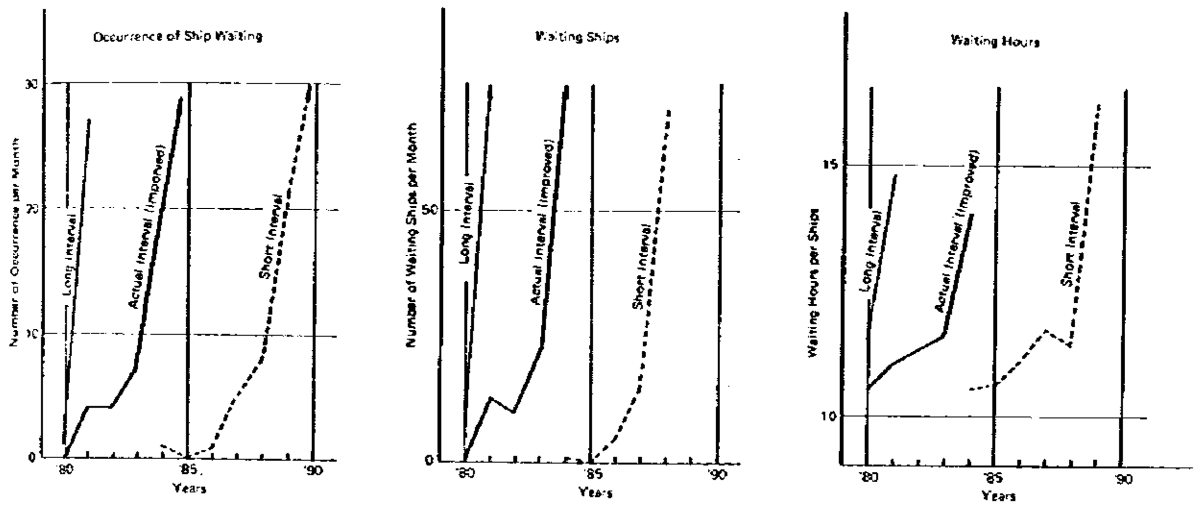


Fig. 7-4-7 Effect of Time Interval Changed between Ships

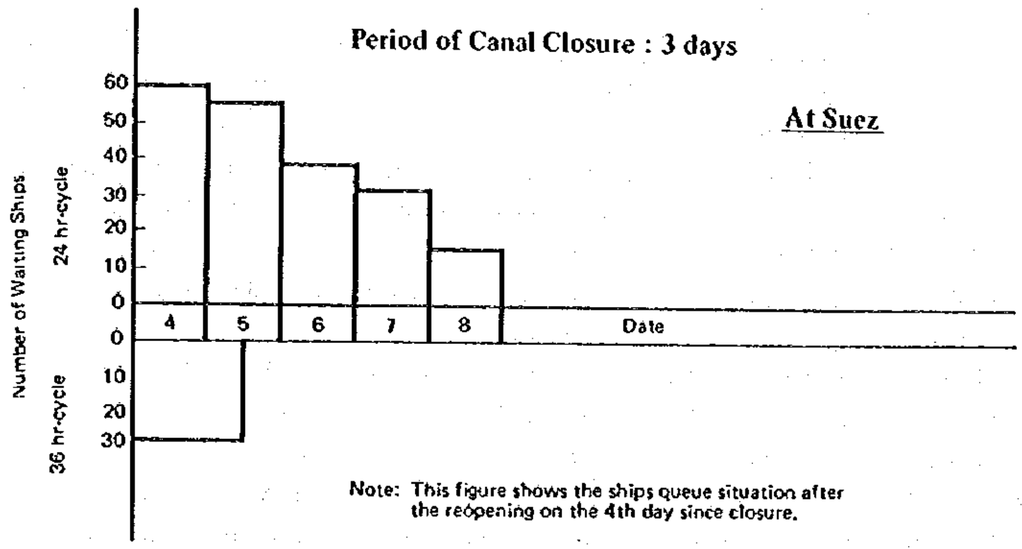
4-4-2 Coping with waiting ships during congestion

If the Canal is closed to traffic due to accident or weather conditions, waiting will occur at Suez and Port Said. In this section a simulation model is to be used to ascertain how waiting ships can be cleared after the closure of the canal for 3 days and 7 days. Further, a study was made as to how many waiting days may be reduced by means of switching over from the current 24-hour cycle transit system to a 36-hour cycle system. Clearing of waiting ships at Suez by both system is shown in Fig. 7-4-8.

Fig. 7-4-8 shows the results of clearing by both the current 24-hour cycle system and the 36-hour cycle system after the closure of the Canal for 3 days and 7 days sometime in 1981.

In the case of a 3-day closure, it takes 5 days under the current 24-hour cycle system to clear the waiting ships, whereas it takes less than 2 days under the 36-hour cycle system. In the case of a 7-day closure, it takes 17 days under the former method and 6 days under the latter. This is because of the larger transit capacity under the 36-hour cycle system and suggests that this cycle system may well be used tentatively in emergencies.

If an accident actually occurs, those vessels which use the Suez Canal may not necessarily wait at Port Said or Suez and some of them may well be diverted to the route via the Cape of Good Hope. Accordingly, the actual period of clearing the waiting ships is expected to be below the results of the simulation test.



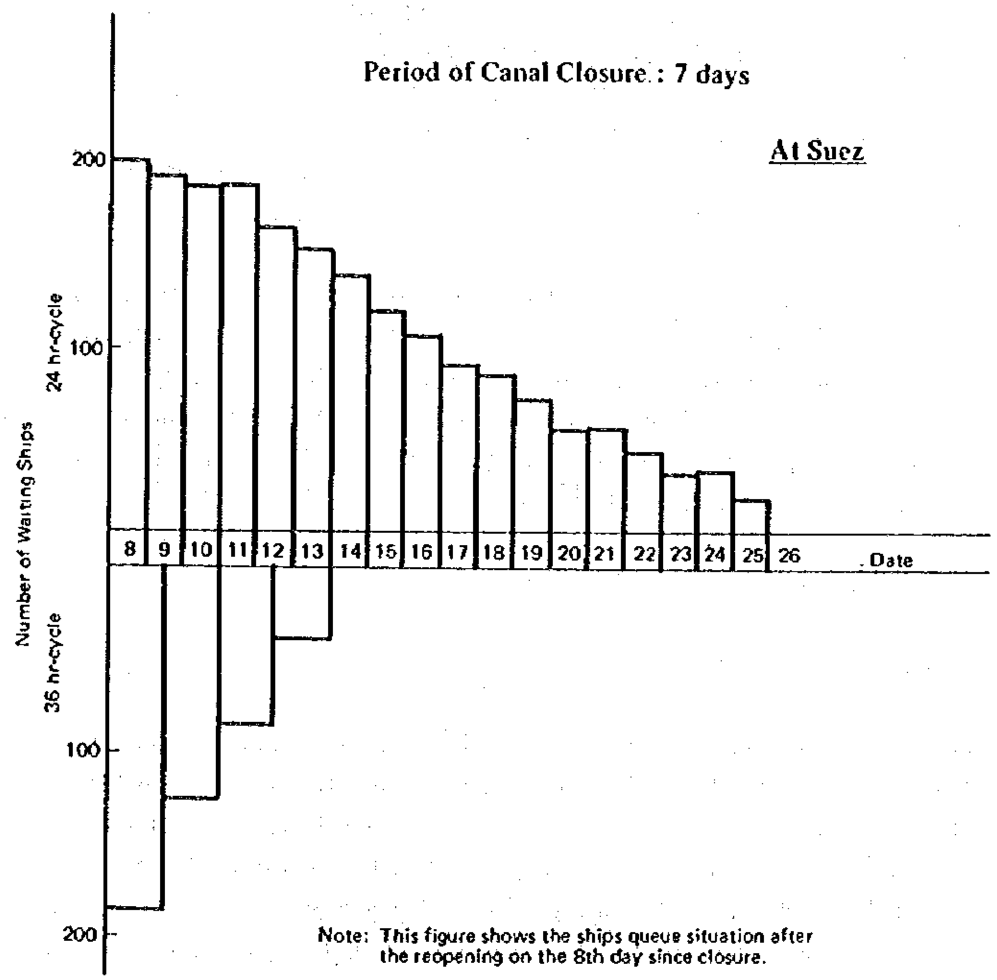


Fig. 7-4-8 Ship Waiting after the Canal Closure (1981)

5. Transit Capacity and Transit Scheme under the First and Second Stage Projects

5-1 Transit capacity under the First Stage Project

The system of one northbound convoy (non-stop) and two southbound convoys (each waiting in the Great Bitter Lake and Ballan Bypass for the passage of the northbound convoy) as in the past, is assumed as the transit system for the period after the completion of the First Stage Project (see Fig. 6-3-2).

The results of a simulation test on ship queuing after the completion of the First Stage Project are shown in Figs. 7-5-1 – 7-5-3. The monthly number of occurrences of ship waiting is 0 in 1980 and 4 in 1981, and gradually increases from 1982 to nearly 30 in 1984. This number is the total at Port Said and Suez, with half occurring at each port. In the results of the simulation test, the level resulting in ship waiting no more than one or two days a month – the target in Part VI – is to be reached in 1981, thus equivalent to the result of the Part VI study from the demand curve and the standard transit capacity. In the results of the simulation test, the number of ship queues is not serious until 1983, but, in 1984, continuous queuing is likely to occur. This is clear also from the increase in the number of waiting ships and waiting hours in Fig. 7-5-2 and 7-5-3. Accordingly, unless the transit capacity is increased by 1984 at the latest, there will be an increase in the number of ships diverting to the route via the Cape of Good Hope instead of the route via the Suez Canal. If this tendency first starts with large ships and then reaches down to smaller ships, there is the fear of a drastic decrease in the Canal revenue.

The above is concerned with the Base Case of demand. In the case of the High Case of demand occurs, continuous ship waiting is forecast, in 1982, and the situation will be more serious.

To avoid this outcome, the Canal must be doubled as soon as possible to increase its transit capacity. But as a provisional measure, a new transit system of N-1 and S-3 convoys may be used, by forming a small convoy using the Timsah Lake to wait for the N-1 convoy, as stated in 3-4-2 of Part VI. The results of a simulation test conducted on this transit system are shown in Fig. 7-5-4. There is the prospect that ship waiting from 1981 can be avoided to some extent by organizing a additional small southbound convoy.

5-2 Transit capacity under the Second Stage Project

5-2-1 Transit capacity under Phase I

For the transit system under the Second Stage Project, no southbound convoys can operate non-stop at Step 1 of Phase I (Plan 1-2) but, after the completion of Phase I (Plan-3), non-stop convoys can operate in both northbound and southbound transit. At Step 1, the transit hours of non-stop southbound convoys can be obtained, if part of the northbound convoy also waits in the Great Bitter Lake. But here, the study of transit capacity is the main aim; accordingly, non-stop transit is used for all northbound convoys as in the past, and for some part of southbound convoys.

Ship waiting in accordance with steps of development of the Second Stage Project is as shown in Fig. 7-5-1 – Fig. 7-5-3.

In the results of this test, the monthly number of queues after the completion of Step 1 (Plan 1-2) is 0 until 1988, but continuous ship waiting is expected to occur suddenly in 1989. In theory, ship waiting increases only gradually but if, as these results show, nearly continuous ship waiting occurs in 1989 after zero in 1988, it is likely that there will be queues even in 1988. In this sense, the situation is much the same as the results discussed in 4-4-2 in Part VI.

The monthly number of queues after the completion of Phase I (Plan 3) is 4 in 1990 and 10 in 1992, with continuous waiting from 1993. One or two days of ship waiting a month was forecast for 1992 in 4-4-2 of Part VI, but from the results of this test, ship waiting may start earlier than that.

The above analysis is concerned with the Base Case of demand, but in the High Case, continuous ship waiting is expected in Step 1 to occur in 1987 and in Phase I from 1989.

Therefore, even if the Base Case of demand continues, it is necessary to complete Phase I in 1987 at the latest, even Phase I can only meet demand until about 1992. If the demand continues to increase at the High Case, Phase I must be completed by 1984 and even this phase can only meet demand until about 1988.

5-2-2 Transit capacity under Phase II

Phase II of the Second Stage Project includes a step (Plan 4) and the Km145--162 section to be doubled to accomplish the entire doubling of the Canal (Plan 5).

As discussed in the preceding "Transit capacity under Phase I", the transit capacity under Phase I becomes saturated in 1992 even if the demand continues at the Base Case rate, and thus the transit capacity must be increased to the step of Plan 4. But even in Plan 4, continuous ship waiting is expected to occur in 1995, and complete doubling of the Canal must be realized by that year, as can be seen from Fig. 7-5-1 – Fig. 7-5-3. If the demand continues to increase at the High Case rate, transit capacity must be increased to the Plan 4 by 1984, but it still may be saturated in 1988.

The results of simulation test for the cases of Existing and Plan-1-2 showing daily transit situation for the period of three days are as indicated in Figs. 7-A-1, 7-A-2 and 7-A-3 at the end of this Part.

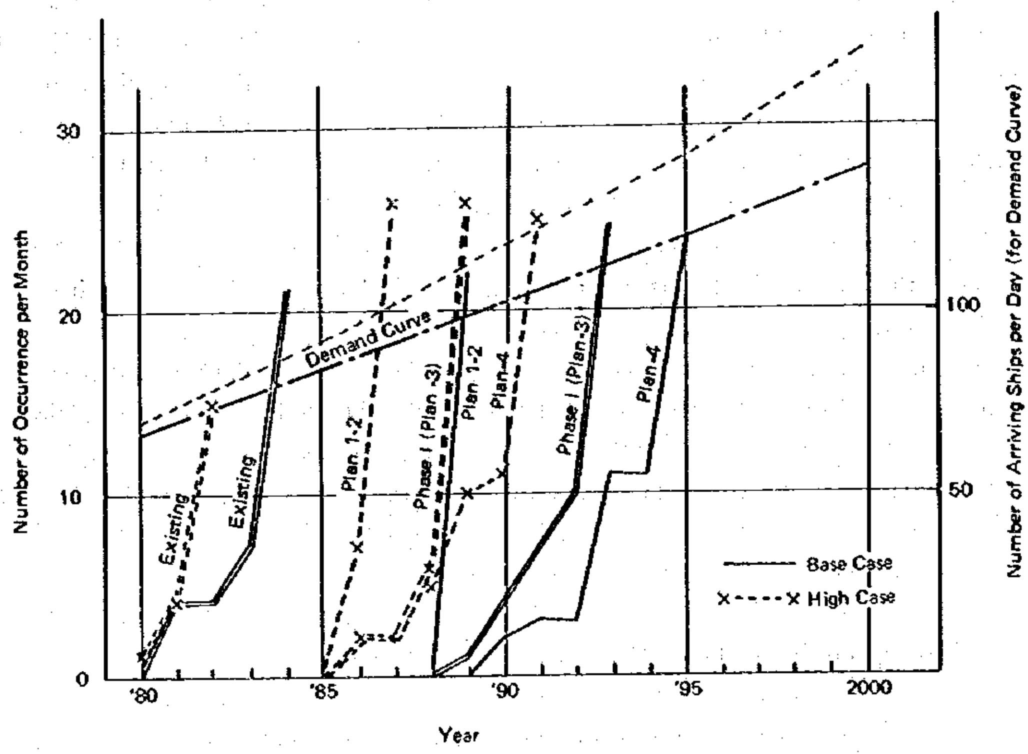


Fig. 7-5-1 Occurrence of Ship Waiting

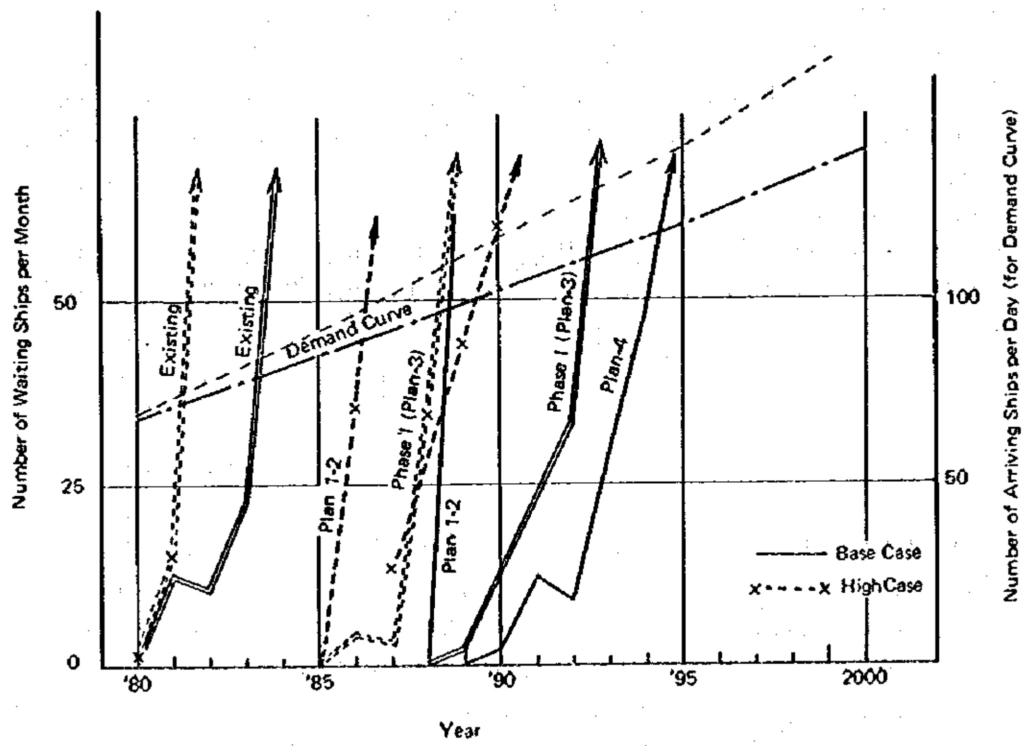


Fig. 7-5-2 Waiting Ships

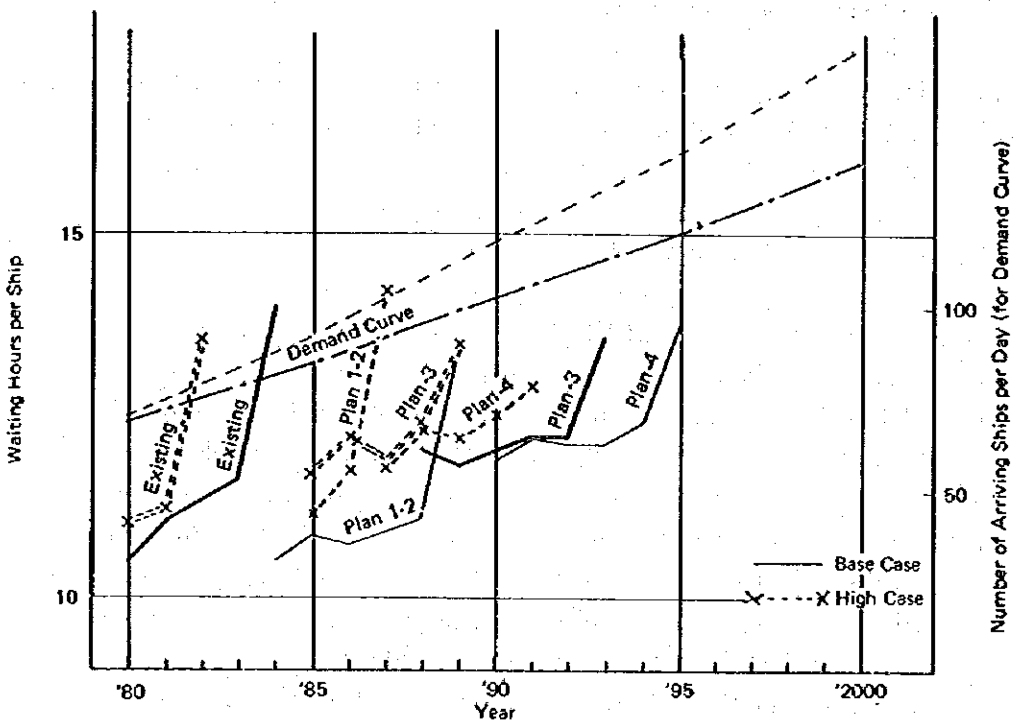


Fig. 7-5-3 Waiting Hours

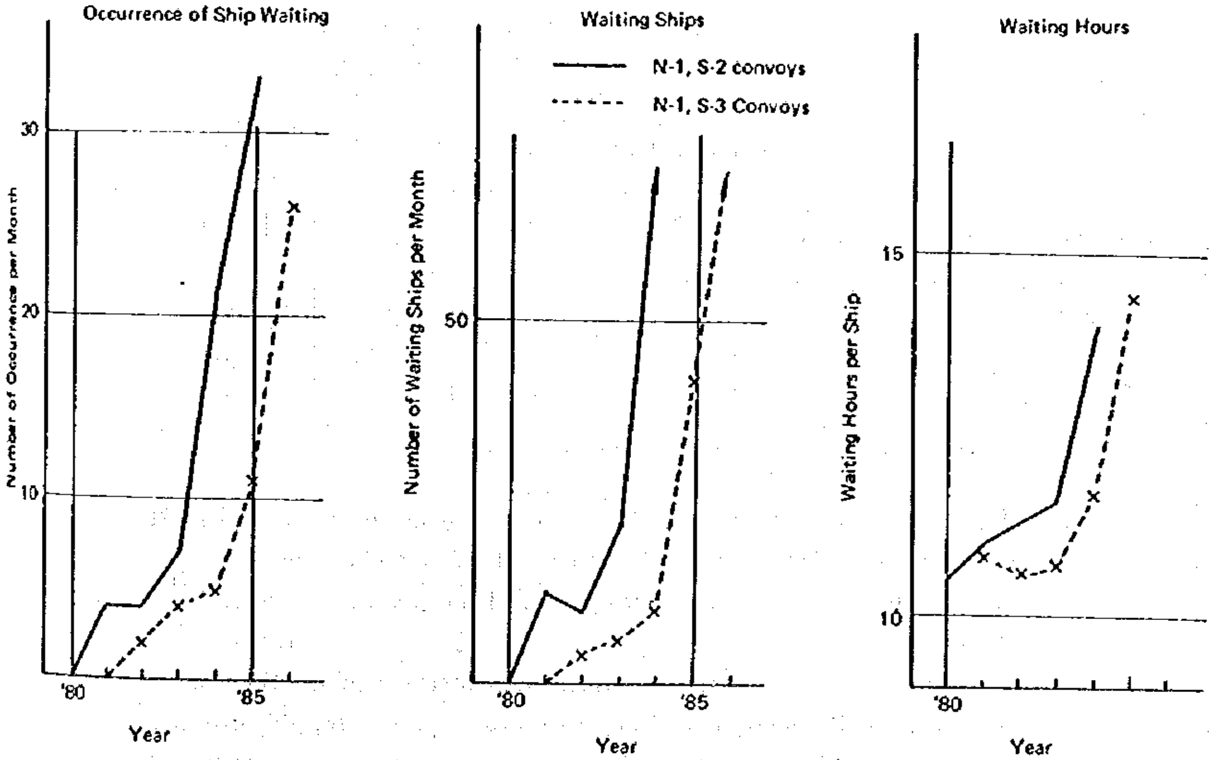


Fig. 7-5-4 Effect of Modified Transit System (N-1, S-3 Convoys)

5-3 Consideration concerning transit system

The followings are the technical and systematic studies of the Canal transit after the completion of the First and Second Stage Projects(Phase I). These studies are made based on the results of the above-mentioned studies.

5-3-1 Technical tasks involved in the Canal transit

(1) Problems arising out of the transit of VLCC

1) Emergency stop in the Canal

a) A VLCC has much greater inertia because of its size than a conventional ship and her speed control is extremely difficult. For her steering ability, the rudder effect is so small that it takes long time to begin turning. Thus, the difficulty in estimating her inertia and the great errors involved in this estimate make steering very difficult. The difficulty is also due to the fact that the pilots of a VLCC relies mainly on his eyesight for information necessary for the steering, and his perception cannot be fully utilized in steering a giant ship.

The steering of VLCC in the Canal is, indeed, difficult because of the narrow and shallow waterway, as well as the effects of the apparent mass and the moment of inertia of the vessel. Furthermore, the effect of tidal current in the southern part of the Suez Canal, the effect of wind,poor visibility and other unfavorable natural conditions are major factors to affect the safe navigation of large tankers.

b) The stopping distance of a large tanker from the time of the start of a full stern during her navigation until it comes to a complete stop is said to be 10 – 16 L. The stopping distance is proportional to the initial speed.

Stopping Distance (full load)

Nav. Speed	Time & Distance	DWT 60,000	80,000	100,000	120,000	140,000	160,000
8 Kt	Time	4m–55sec	5–50	6–20	7–30	8–40	9–00
	Distance	720m	820	1,000	1,100	1,200	1,300
6 Kt	Time	3m–40sec	4–20	4–40	5–25	6–00	7–00
	Distance	500m	560	680	720	840	980

Source: Japanese Dockmasters' Association 'Dockmaster No. 37'.

c) The stopping distance derived from reverse engine thrust under ballast condition (50% of full load) is about 80% of that under full load condition.

d) In restricted waterways the extra mass and hull resistance increase, if the water depth is shallow.

The increase of extra mass means an increase of inertia and the stopping distance, but the increase of hull resistance decreases stopping distance. Stopping distance in case of a stopped engine and a reversed engine is shortoned in proportion to a smaller h/d, and is said to be 92% at h/d = 2.0 and 83% – 85% at h/d = 1.5.

e) If, during the navigation in the Canal, an accident occurs to a large tanker or a ship proceeding in front, the following tanker must stop urgently.

It is only in case of emergency that a large tanker must stop by a full stern. In this event, the bow of a ship with a right-turning single screw is theoretically supposed to swing to right but, in a test conducted with large tankers by a Japanese dockmaster, swing to left occured in nine out of the 22 instances and the swing by the same ship is sometimes to right and sometimes to left, even when the relative wind direction is approximately equal.

Of course, the swing is closely related to wind direction, tidal current, trim, ship size and other factors. However, whether the swing is to right or left can be seen only by actually causing a full stern to the ship. Such swing is said to be totally random with large tankers.

f) Generally, any large ship maintains approximately her original course for the first two minutes after a full reverse engine thrust with little swing of her bow. After two minutes the bow begins slowly to swing to right or left, and the swing suddenly increases in about four minutes. The turning inertia increases with the length of time of a full stern and the decrease of stopping distance.

In a channel, with its extremely small steering area, it is impossible for a larger tanker to stop herself without landing on banks.

To stop a large tanker along the waterway, therefore, it is practical to cause a sternway to the ship for about two minutes at the first and correct her bow swing, using the rudder or tugboats, and then after slowly reversing the engine for deceleration, decelerate the ship further using tugboats, and thus stop the ship parallel to and in the middle of the waterway.

g) With the assistance of powerful tugboats, it would be possible for a large tanker navigating the Canal at 7 kt to be stopped in a distance of 4 – 6 L, if the effects of wind and tidal current are small.

2) Number of tugboats necessary for Canal transit

a) Tugboats usually attend a large tanker navigating restricted waterway to relieve her difficulty in steering.

The results of a survey on the use of tugboats at Japanese ports and foreign ports with oil terminals are as follows:

Attendance of Tugboats on Large Tankers

Japanese Ports (full Load)		Foreign Ports (ballast)	
DWT	No. of Tugboats	DWT	No. of Tugboats
Less than 60,000	2	Less than 60,000	1 – 2
60,000 – 100,000	2	60,000 – 130,000	2
100,000 – 150,000	3 – 4	130,000 – 150,000	2 – 3
150,000 – 200,000	6	150,000 – 200,000	3 – 4

Source: Materials compiled by the Japan Association for Preventing Marine Accident

b) The required horsepower of tugboats assisting the steering of a fully laden large tanker in Japanese ports is 6 – 7% of freight tonnage for tankers of 150,000 – 200,000 DWT. Thus, it is 9,000 – 10,500 HP for a 150,000 DWT tanker. Since the horsepower of a tugboat is usually in the 3,000 HP class, three or four tugboats are necessary for a tanker of this size. In the case of departure, the required horsepower of tugboats is taken about 60% of the horsepower at the arrival.

c) A large tanker navigating a canal must make an emergency stop in the event of engine trouble or the engine trouble of a ship proceeding in front, strong wind, poor visibility or some other reasons. In case of the Suez Canal the number of escort tugboats can, unlike tugboats assisting ship steering in the foregoing ports, be limited to the necessary minimum for the following reasons:

   a. There is a large intervals between ships, unlike ports where ship traffic is congested.
   b. There is a system by which related ships can be immediately notified in case of an accident and thus ships in the rear can readily take necessary actions. (There is sufficient time intervals between ships).
   c. In Canal navigation, accurate steering, such as turning in front of a berth and berthing a ship alongside a pier, is not required.
   d. In the Canal, tugboats are used only for braking in case of emergency stops, assisting the maintenance of course against wind or tidal current and for mooring of ships in the Canal by ways.
   e. Tugboats engage in accurate initial rescue work in case of fire, oil leak or stranding.
   f. During the transit of a convoy, assistance can be expected from tug boats escorting nearby tankers unrelated to an accident.
   g. Four salvage tugboats are always on standby in the Great Bitter Lake, ready to assist.

d) Factors that must be considered in deciding the minimum number of tugboats are as follows:

   a. Brake horsepower: The limit speed for tugboats is about 5 kt. They are used to brake a ship in about this speed. For this purpose, they need the sufficient horsepower against the total hull resistance of the ship.

Required Horsepower against Hull Resistance

Vessel size (DWT)	Total resistance against 5 Kt. towing		Required horse-power to stop (HP)	Number of tugboats (No.)
	Full (R)	1/4 Load (ton)		
50,000	26.3	14.0	2600	1
75,000	33.3	19.2	3300	1
100,000	39.8	21.6	4000	1
135,000	49.5	26.4	5000	2
200,000	64.1	34.0	6400	2
275,000	76.4	40.3	7700	2

Note: $R_{fW} + R_3 + R_f = R$ $R_3 \doteqdot 1.3 \times R_{fw}$

Standard Towing Power of Tugboat

Type of tugboat	Towing power per 100 HP	
	Forward (ton)	Reverse (ton)
V.S.P.	1	0.7
C. P. P.	1.35	0.75
Z type	1.5	1.2

b. Sufficient ability to bear the wind pressure during canal transiting.

Wind Pressure by Vessel Size (ton)

Displacement	Wind Direction / Speed (m/sec)	Wind Pressure					
		Bow-stern (0°)			Beam (90°)		
		8	12	16	8	12	16
DWT 50,000	*F	0.7	1.6	2.8	5.9	13.2	23.6
	B	1.2	2.7	4.8	10.0	22.5	40.1
75,000	F	1.0	2.8	4.0	8.0	18.0	31.9
	B	1.7	3.8	6.9	13.6	30.6	54.0
100,000	F	1.1	2.5	4.3	8.3	18.7	33.3
	B	1.9	4.3	7.3	14.1	31.8	56.6
135,000	F	1.5	3.5	6.3	11.5	26.0	46.0
	B	2.6	6.0	10.6	19.6	44.2	78.2
200,000	B	3.8	8.5	15.2	20.4	45.3	81.6
275,000	B	5.2	9.2	16.3	39.0	68.3	121.5

*Note: F = Full load   B = Ballast (50% full)

c. Sufficient ability to bear the pressure by tidal current.
The tidal current in the south of the Great Bitter Lake is 4 km/h (2.16 kt) at maximum and it greatly affects the steering of a large tanker. Current pressure in the bow-stern direction affects the braking and stopping distance of a ship. Current pressure in the beam direction causes a leeway which, if it is large, sometimes makes the maintenance of the ship's course direction difficult.

Current Pressure by Vessel Type (1/4 load)

(ton)

Type (DWT)	1 Kt.		2 Kt.	
	Bow-stern	Beam	Bow-stern	Beam
50,000	0.5	8.2	1.8 (6)	30
75,000	0.6	9.8	2.2 (7.5)	36
100,000	0.8	14.0	2.6 (8)	43
135,000	0.93	15.5	3.2 (10)	52.5
200,000	1.2	19.5	4.0	66
275,000	1.6	26.2	5.6	82

Note: ( ) Full load

It is extremely difficult to determine the minimum number and horsepower of tugboats to be used in Canal navigation since ship size, draft and topography, shape and water depth of the Canal and wind and tidal current pressure are deeply correlated.

An attempt at determining the required number of tugboats, according to ship size, is tabulated below:

Preconditions
Wind: Wind of 12 m/sec in the direction of beam
Tide: Tidal current of 2 kt at maximum and parallel to waterway

Required Tugboats by ship type

Ship Size (DWT)	Hull Resistance in transiting at 5 Kt (tons)	Wind (beam) 12 m/sec (tons)	Tidal current (Bow-stern) 2 Kt (tons)	Total (tons)	Required number of tugboats
50,000	26.3	13.2	6	45.5	1
	(14.0)	(22.5)	(1.8)	(38.3)	1
75,000	33.3	18.0	7.5	58.8	2
	(19.2)	(30.6)	(2.2)	(52.0)	1
100,000	40	18.7	8	66.7	2
	(21.6)	(31.8)	(2.6)	(56.0)	1
135,000	49.5	26.0	10	85.5	2
	(26.4)	(44.2)	(3.2)	(73.8)	1
200,000	(34)	(45.3)	(4.0)	(83.3)	2
275,000	(40)	(68.3)	(5.6)	(113.9)	3

Note: (1) Each tugboat should have 3000 HP (duck propeller) and bollard pull of 45 tons.
(2) ( ): Case of 1/4 load.

Therefore, the required number and capacity of tugboats are as follows;

Size (DWT)	Transit of full load Capacity	No.	Transit in ballast Capacity	No.
Up to 60,000	3000 HP or over	1	3000 HP or over	1
60,000 – 150,000	〃	2	〃	2
200,000 over	–	–	〃	3

Since the number of tugboats and the wind and tidal current pressure are correlated, conditions (wind and tidal current) for the suspension of canal navigation of large tankers must be made more strict than ever, if the use of tugboats is reduced.

In this study, accordingly, taking into consideration of the number of existing escort tugboats and the increase of transit tankers, the required number of tugboats at the year of 1990 is estimated as follows;

Year	Required Number of Tugboats (Total)	Number of Existing Escort-tugs	Number of Escort-tugs introduced
1990	33	15	18

Note: A capacity is 3000 HP or over.

(2) Time interval between large tankers

Assuming that a large tanker transiting the Canal is always escorted by two tugboats of 3,000 HP or over, as stated above, the stoping distance of a large tanker is 4 – 6 L. In considering time intervals between ships in a convoy, such factors as the steering ability of ships, master and pilot, the power and number of tugboats, the danger of the cargo, the type of accidents, natural conditions in case of accidents and time required for communications must be studied carefully.

It is very important in adopting a time interval that the opinions of pilots engaged in actual piloting should be fully respected. Assuming from the above that the safety factor of stopping distance is 2, the stopping distance of a 150,000 DWT tanker is:

$$12\,L \doteq 3480\,m$$

So, the time interval between ships is 16.6 minutes.

Whereas, the present interval between ships loaded with radioactive material is 20 minutes (4 km) and the present interval between loaded tankers (16,000 tons or over) is 16 minutes (3.5 km).

It would, therefore, be convenient for control and piloting to use the same interval of 16 minutes (3.5 km) for VLCCs as for other tanker groups.

Fifteen minutes is used as the time interval between VLCCs for waterway control in the Bay of Tokyo and generally satisfactory results are obtained from this interval.

5-3-2 Canal transit scheme

(1) Various schemes for increasing transit capacity

Methods to increase the transit capacity of the Canal were examined in 4-4 of this Part VII besides doubling the Canal as below.

1) Increasing the transit cycle time (36-hour cycle)
2) Allowing two-way traffic to small ships
3) Speed-up
4) Decreasing time intervals between ships

Speed up

This scheme is technically difficult because of speed limitation in restricted water. Even if speed-up is realized by solving the technical problems, drastic capacity increase cannot be achieved according to the results of examination in 4-4 of this Part VII. Further, the effect of speed-up is small if any convoy includes a single slow ship, because ships proceeding in the rear of a slow ship cannot but keep pace with her. Rather, garages for waiting of slow ships should be provided at some points of the Canal so that convoys, as a whole, can maintain speeds set by the Rules of Navigation.

Decreasing time interval between ships

This scheme is considered possible to some extent if the navigation control system is improved. The present time intervals between ships are sufficient in view of the examples of Japanese navigational conditions, even considering the special condition of restricted channel. Decreasing time intervals to a certain extent may be possible if the SCVTMS to be operated after the First Stage Project becomes reliable but this should be limited to small general cargo ships of which the speed adjustment is relatively easy.

Allowing two-way traffic to small ships

This scheme is fairly effective for the increase of transit capacity. This is assumed to be limited to ships (excluding container ships and tankers) of less than 7,000 DWT but the present width of the canal is not sufficient in consideration of such factors as temporary gusts of wind. This scheme goes against the purpose of enhancing navigational safety and will require the installation of complex navigation aids and traffic control in the Canal, resulting in the subject requiring further study.

Increasing the transit cycle time

This scheme is likely to increase transit capacity without any drastic improvement of the Canal. But to users, the employment of this scheme will cause the deterioration of services. First, there is a problem of increased time required of ships waiting for the departure of the next convoy at Port Said and Suez.

Second, the time of departure from both ends of the canal under a 36-hour-cycle system is not so regular everyday as it is under the 24-hour-cycle system, thus confusing the users. Third, it is desirable for navigational safety to enable LNG ships, LPG ships and other ships carrying dangerous cargoes to transit the Canal in daytime in so far as possible, but this arrangement is impracticable every other day in the case of a 36-hour cycle. These inconveniences for users are expected to arise, and the SCA may suffer most from the decrease of its Canal revenue if some large tankers switch to the route via the Cape of Good Hope from the Suez Canal due to poor services and consequent economic reasons.

Furthermore, the SCA will face complicated problems, such as labor management and the increase of navigation aids due to the change of the 24-hour-cycle system which has long been familiar to the SCA.

The international role of the Canal makes it imperative to improve services for users rather than force deteriorated services upon them.

Therefore, the scheme of extending the cycle time should not be employed permanently for Canal transit. Instead, it should, as discussed in 4-4, be effectively used as a temporary arrangement for special occasions, such as the waiting of a large number of ships on the Port Said and Suez due to an accident in the canal, inclement weather or some other reasons.

(2) Transit system after completion of the Second Stage Project

The past system of one northbound convoy (non-stop) and two southbound convoys will be continued after the completion of the First Stage Project, but under the Second Stage Project, it will be possible to start non-stop transit for part of the southbound convoys from Step 1 of the Phase I, as indicated in Fig. 6-3-5. Accordingly, it will be possible to operate southbound convoys by the following groups:

S-1: General cargo ships and bulk carriers (to wait in the Bitter Lake)

S-2: Tankers and container ships (non-stop)

After the completion of Phase I all southbound convoys can transit non-stop, drastically improving transit conditions from the standard of the First Stage Project.

However, since the west channel adjacent to the New Port Said By-pass is not yet ready at Phase I, southbound VLCCs and large container ships will use the New Port Said By pass in their southbound transit before northbound ships use it.

When the new transit system is adopted, it is no longer necessary for southbound ships to wait in Ballah By-pass or Great Bitter Lake. This Lake will be only used for shelter in case of problems.

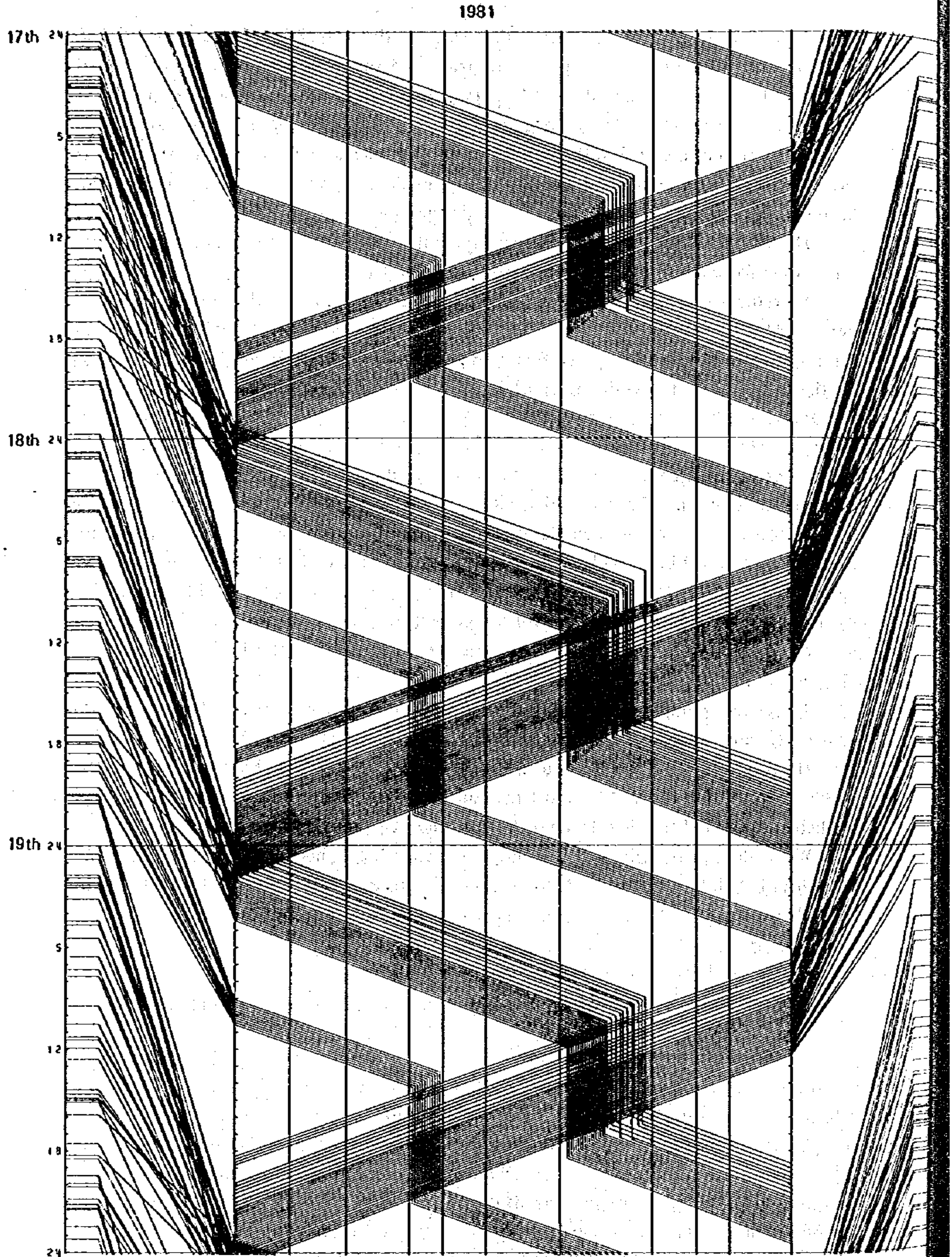


Fig. 7-A-1 Transit Diagram Made By Simulation Test (Existing Canal, 1981)

1984

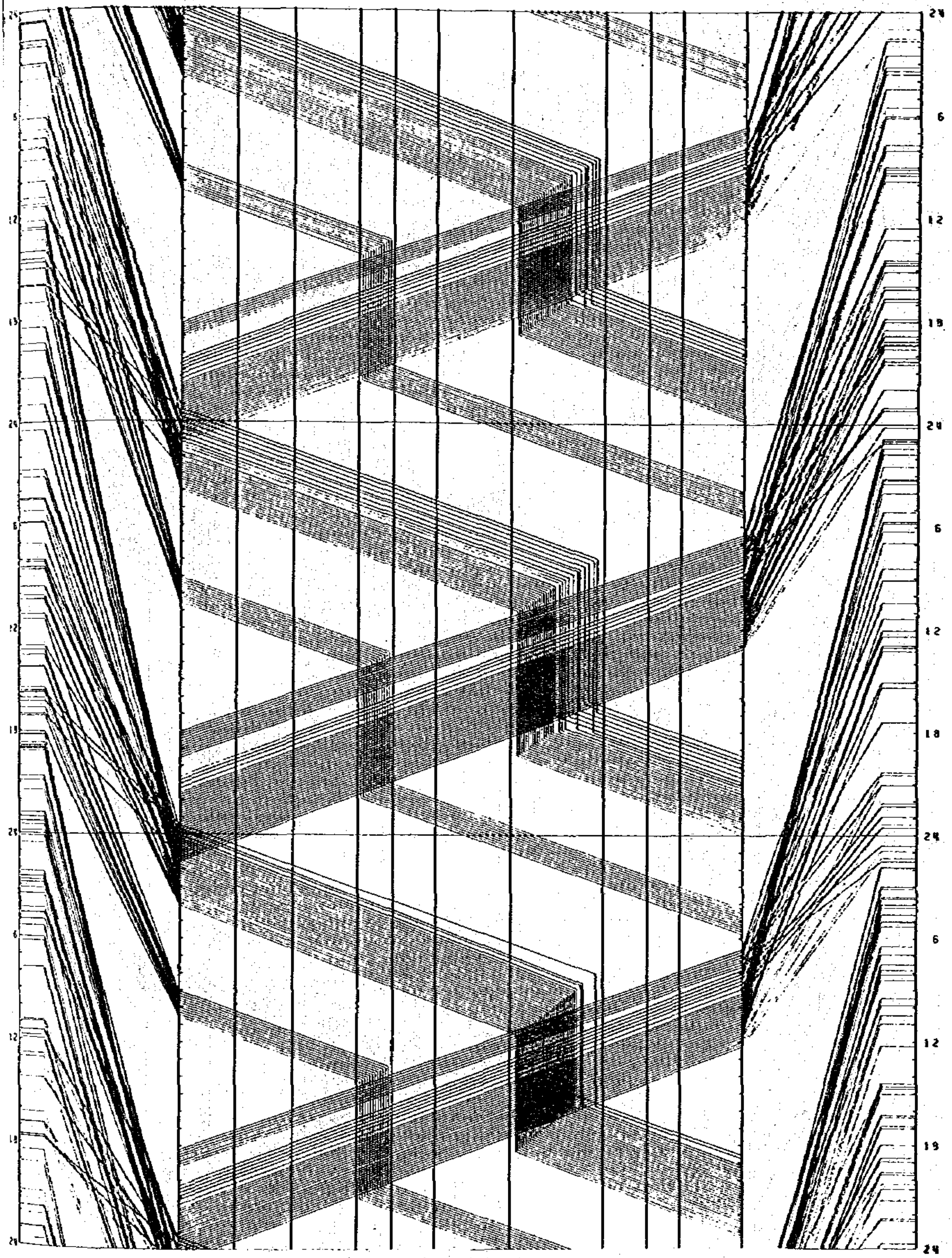


Fig. 7-A-2 Transit Diagram Made By Simulation Test (Existing Canal, 1984)

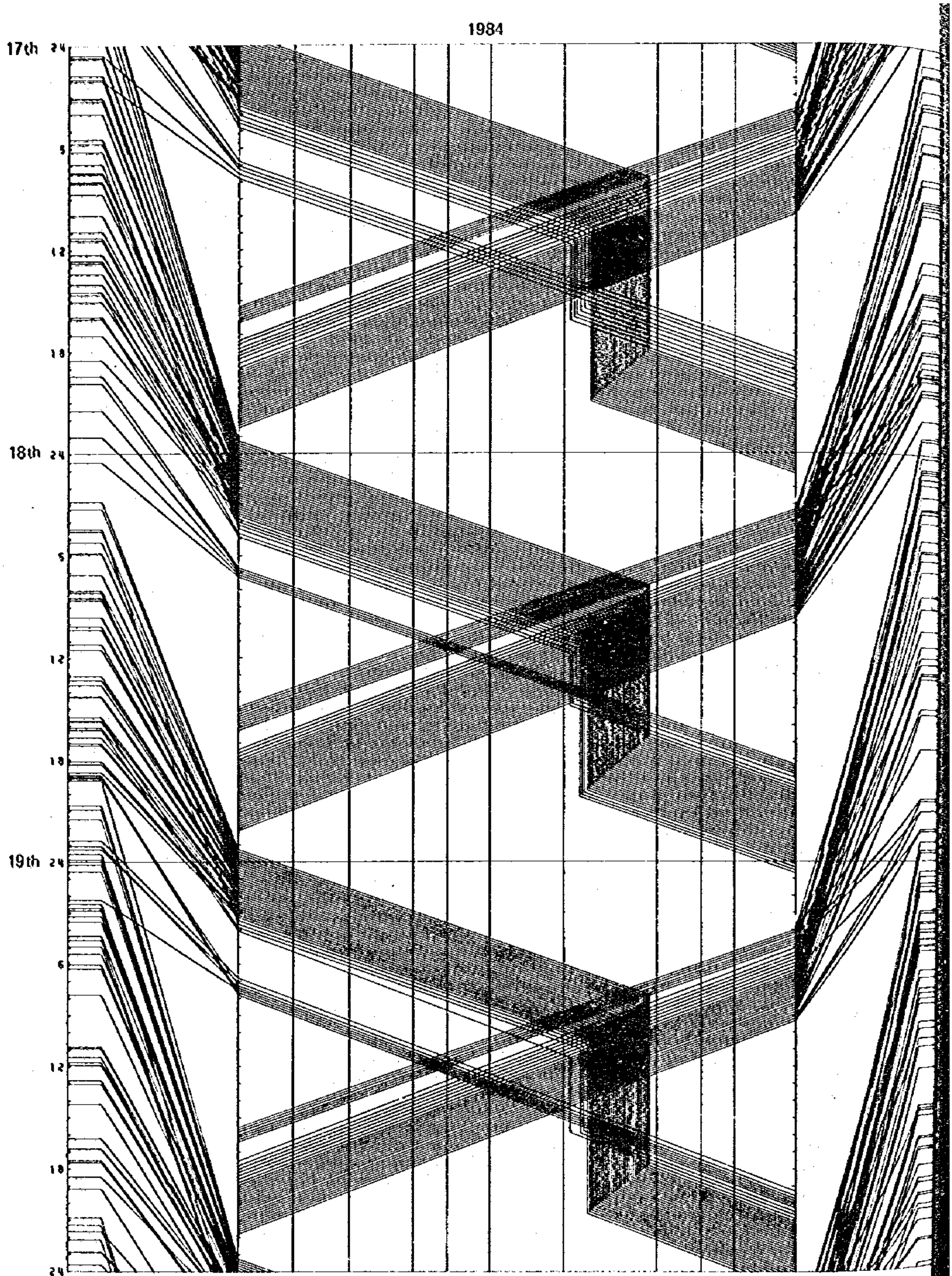
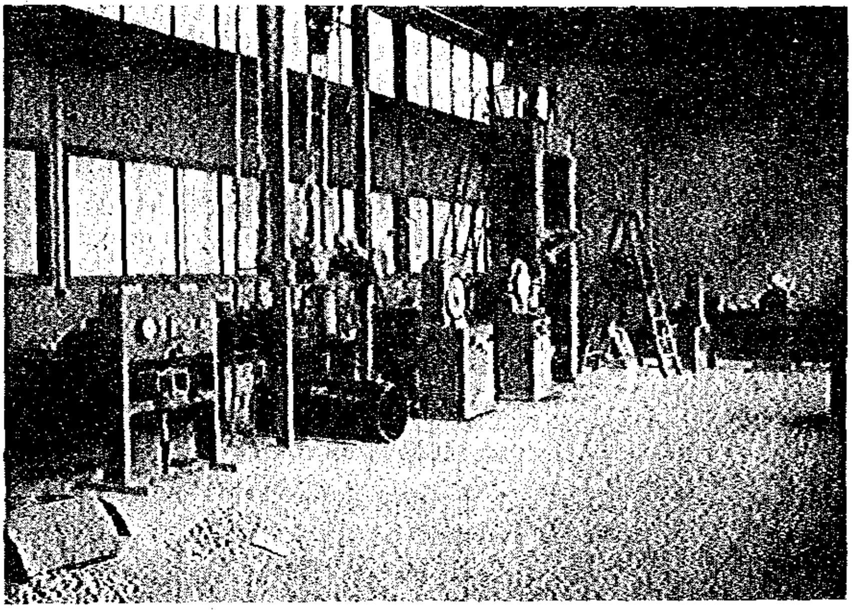


Fig. 7-A-3 Transit Diagram Made By Simulation Test (Step 1, Phase I, 1984)



VIII. Technical Examination

PART VIII TECHNICAL EXAMINATION

Part VIII is devoted to a technical examination of the various problems expected to arise during the development of the Canal. As described in preceding Parts, the Canal is, to meet an increasing transit demand in the future, to be expanded and/or doubled. The maximum ship size considered in the Second Stage Project is around 150,000 DWT and 250,000 DWT in the Master Plan, and the Canal is to be doubled for the reach of km 0 – 135 under the First Phase of the Second Stage Project and for the entire reach thereafter. The cross section of eastern channel, shall be about 3500 m^2 with the depth of 19.5m under the Second Stage Project. With increase in ship size, the Canal sections expanded and/or doubled give rise to problems in the maneuverability of transit ships, the stability of the Canal bank, etc. Of these problems, followings are notable, i) hydraulic phenomena due to transit ii) maneuverability of VLCCs iii) tidal current in the expanded canal iv) stability of the canal bank v) siltation rate in the developed Canal.

Problems described above have been examined in detail, prior to the First Stage Development of the Canal. For instance, the Canal sections proposed for the Second Stage and Master Plan in this Study have been examined by Coopers & Lybrand Associates Ltd./Maunsell Consultants Ltd. and by Sogreah through analysis using hydraulic model and numerical calculation. As the main purpose of the Study is to frame out the optimum plan after completion of the First Stage Development Plan from an economical viewpoint, the Canal sections have been designed based on the results obtained in the past studies.

Basic factors taken for designing will be described and reviewed and the results of analyses obtained newly will be discussed in this Part.

1. Hydraulic Phenomena due to Ship Transit

Various hydraulic phenomena are induced by ships transiting the Canal; their characteristics depend on ship size, ship speed and Canal section. These phenomena may be classified into i) drawdown ii) return current and iii) ship wave, all of which affect the stability of bank and revetment. A detailed discussion on the stability of the Canal in the Second Stage Project and Master Plan are given below.

1-1 Drawdown

Water mass in front of transiting ship is displaced and flows toward the stern, this is called as a return current. At the same time water level along the both sides of ship draws down. This temporary lowering of water level affects the stability of revetment, by increasing a residual water pressure, and this may cause surge waves on berm when the water depth on it is insufficient.

According to the results of the studies mentioned previously, drawdown Δd is given by the following equation.

$$\Delta d = 8.8/Ra^{1.4} \cdot Vs^2/2g = 0.449\ Vs^2/Ra^{1.4} \quad (1)$$

where, Ra .... Area Ratio

Vs .... Ship Speed

g .... Acceleration due to gravity

Drawdown is shown in Fig. 8-1-1 and Table 8-1-1. As shown, drawdown increases with increasing ship speed and decreasing area ratio, and the maximum is about 80 cm for a west channel with area ratio of 4.7 and ship speed of 14 km/h. This is for the value for the largest ship, while for smaller ships (which transit the Canal more) the area ratio increases and this decreases the drawdown. The drawdown for a ship of maximum size and for a 10,000 DWT class general cargo carrier is shown for each stage of development in Table 8-1-2. As shown in the Table, the drawdown for the maximum ship decreases from 84 cm in the pre-First Stage Development to 65 cm in the Second Stage and Master Plan due to the increased area ratio adopted, and from 20 cm to 5 – 7 cm for 10,000 DWT class general cargo carrier. This decreased drawdown is expected to improve the stability of revetment by decreased drawdown is expected to improve the stability of revetment by decreasing the scouring force acting on it. It has been pointed out that, where the *water depth on a berm is shallow, a surge wave is induced by drawdown and a critical depth for* occurrence of waves, is derived by the following equations:

$$d_b > Vs^2/g\ [4.4/Ra^{1.4} + 1/1.7^2 \cdot Ra^2/(Ra - 1)^2] \quad (2)$$

– to avoid surge waves

$$d_b > Vs^2/g\ [4.4/Ra^{1.4} + Ra^2/(Ra - 1)^2] \quad (3)$$

– to avoid all waves

where, d_b: water depth on berm

The first term of the above equations denotes drawdown, and the second are for the additional depth required to avoid waves on the berm.

A critical depth of wave occurrence is shown in Table 8-1-1 and is of similar characteristics to drawdown. The water depth on berm must not be less than about 3 m to avoid all waves and about 1.5 m to avoid surge waves. These are smaller than the depth at pre-First Stage by about 20 cm. As a surge wave causes adverse effects on the stability of the berms, the water depth on it should be designed to be greater than that which prevents a surge wave.

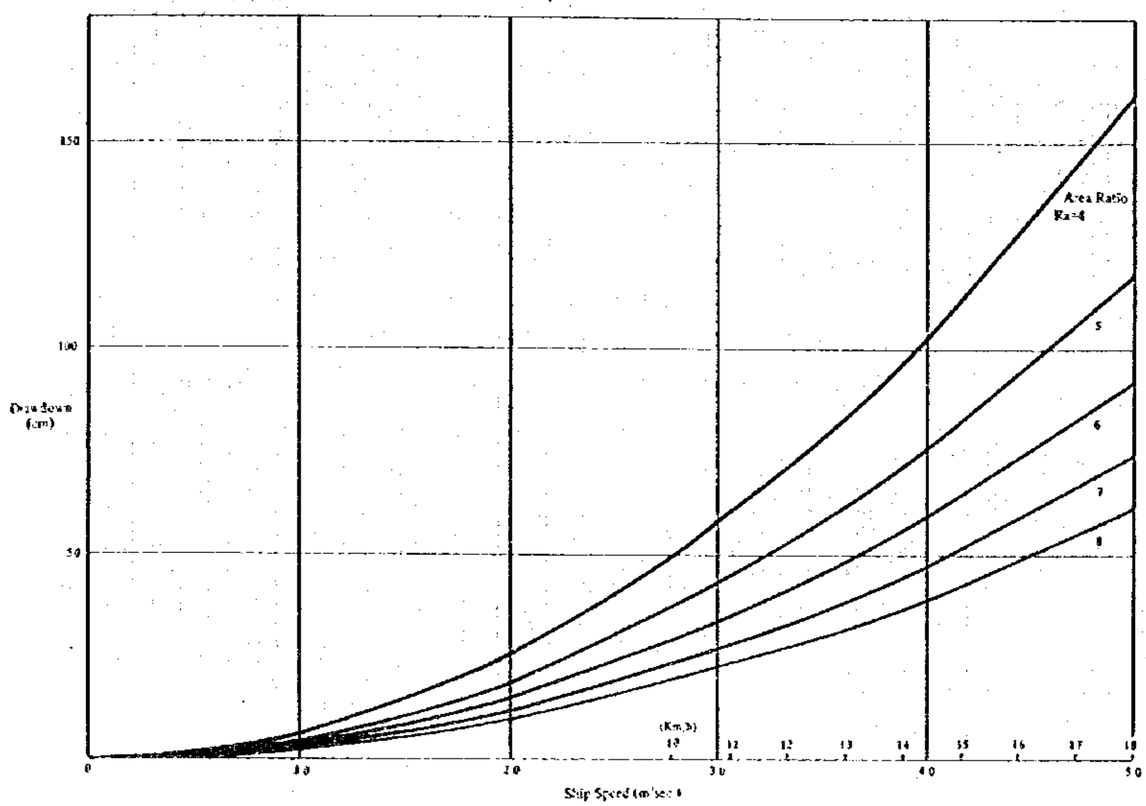


Fig. 8-1-1 Drawdown and Ship Speed

Table 8-1-1 Hydraulic Phenomena

Drawdown (m)

Ra \ Vs	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00
3.00	0.74	0.90	1.07	1.26	1.46	1.67	1.91	2.15	2.41	2.69	2.98
3.50	0.60	0.73	0.86	1.01	1.18	1.35	1.54	1.73	1.94	2.16	2.40
4.00	0.50	0.60	0.72	0.84	0.98	1.12	1.27	1.44	1.61	1.80	1.99
4.50	0.42	0.51	0.61	0.71	0.83	0.95	1.08	1.22	1.37	1.52	1.69
5.00	0.36	0.44	0.52	0.62	0.71	0.82	0.93	1.05	1.18	1.31	1.46
6.00	0.28	0.34	0.41	0.49	0.55	0.63	0.72	0.81	0.91	1.02	1.13
7.00	0.23	0.27	0.33	0.38	0.45	0.51	0.58	0.66	0.74	0.82	0.91
8.00	0.19	0.23	0.27	0.32	0.37	0.42	0.48	0.54	0.61	0.68	0.75
9.00	0.16	0.19	0.23	0.27	0.31	0.36	0.41	0.46	0.52	0.58	0.64
10.00	0.14	0.17	0.20	0.23	0.27	0.31	0.35	0.40	0.45	0.50	0.55
15.00	0.08	0.09	0.11	0.13	0.15	0.18	0.20	0.23	0.25	0.28	0.31
20.00	0.05	0.06	0.08	0.09	0.10	0.12	0.13	0.15	0.17	0.19	0.21
25.00	0.04	0.05	0.05	0.06	0.07	0.09	0.10	0.11	0.12	0.14	0.15
30.00	0.03	0.04	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12

Velocity of Return Current (m/sec)

Ra \ Vs	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00
3.00	1.39	1.53	1.67	1.81	1.94	2.08	2.22	2.36	2.50	2.64	2.78
3.50	1.11	1.22	1.33	1.44	1.56	1.67	1.78	1.89	2.00	2.11	2.22
4.00	0.93	1.02	1.11	1.20	1.30	1.39	1.48	1.57	1.67	1.76	1.85
4.50	0.79	0.87	0.95	1.03	1.11	1.19	1.27	1.35	1.43	1.51	1.59
5.00	0.69	0.76	0.83	0.90	0.97	1.04	1.11	1.18	1.25	1.32	1.39
6.00	0.56	0.61	0.67	0.72	0.78	0.83	0.89	0.94	1.00	1.06	1.11
7.00	0.46	0.51	0.56	0.60	0.65	0.69	0.74	0.79	0.83	0.88	0.93
8.00	0.40	0.44	0.48	0.52	0.56	0.60	0.63	0.67	0.71	0.75	0.79
9.00	0.35	0.38	0.42	0.45	0.49	0.52	0.56	0.59	0.63	0.66	0.69
10.00	0.31	0.34	0.37	0.40	0.43	0.46	0.49	0.52	0.56	0.59	0.62
15.00	0.20	0.22	0.24	0.26	0.28	0.30	0.32	0.34	0.36	0.38	0.40
20.00	0.15	0.16	0.18	0.19	0.20	0.22	0.23	0.25	0.26	0.28	0.29
25.00	0.12	0.13	0.14	0.15	0.16	0.17	0.19	0.20	0.21	0.22	0.23
30.00	0.10	0.11	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19

Required Depth on Berm to avoid all wave (m)

Ra \ Vs	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00
3.00	2.52	3.04	3.62	4.25	4.93	5.66	6.44	7.27	8.15	9.08	10.06
3.50	2.14	2.59	3.09	3.62	4.20	4.82	5.49	6.19	6.94	7.74	8.57
4.00	1.98	2.38	2.73	3.21	3.72	4.27	4.86	5.48	6.15	6.85	7.59
4.50	1.72	2.09	2.48	2.91	3.38	3.88	4.41	4.98	5.58	6.22	6.89
5.00	1.59	1.93	2.30	2.69	3.12	3.59	4.08	4.61	5.17	5.76	6.38
6.00	1.42	1.71	2.04	2.39	2.77	3.19	3.62	4.09	4.59	5.11	5.66
7.00	1.30	1.57	1.87	2.20	2.55	2.92	3.33	3.75	4.21	4.69	5.20
8.00	1.22	1.47	1.75	2.06	2.39	2.74	3.12	3.52	3.94	4.39	4.87
9.00	1.16	1.40	1.67	1.95	2.27	2.60	2.96	3.34	3.75	4.17	4.63
10.00	1.11	1.34	1.60	1.88	2.18	2.50	2.84	3.21	3.60	4.01	4.44
15.00	0.98	1.15	1.41	1.66	1.92	2.21	2.51	2.84	3.18	3.55	3.93
20.00	0.92	1.12	1.33	1.56	1.81	2.08	2.37	2.67	3.00	3.34	3.70
25.00	0.89	1.08	1.29	1.51	1.75	2.01	2.28	2.58	2.89	3.22	3.57
30.00	0.87	1.06	1.26	1.47	1.71	1.96	2.23	2.52	2.83	3.15	3.43

Required Depth on Berm to avoid surge wave (m)

Ra \ Vs	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00
3.00	1.36	1.64	1.95	2.29	2.66	3.05	3.47	3.92	4.40	4.90	5.43
3.50	1.13	1.37	1.63	1.92	2.22	2.55	2.90	3.28	3.67	4.09	4.53
4.00	0.98	1.19	1.41	1.66	1.92	2.21	2.51	2.84	3.18	3.54	3.92
4.50	0.87	1.06	1.26	1.47	1.71	1.96	2.23	2.52	2.83	3.15	3.49
5.00	0.79	0.96	1.14	1.33	1.55	1.78	2.02	2.28	2.56	2.85	3.16
6.00	0.67	0.82	0.97	1.14	1.32	1.52	1.73	1.95	2.18	2.43	2.70
7.00	0.60	0.72	0.86	1.01	1.17	1.35	1.53	1.73	1.94	2.16	2.39
8.00	0.54	0.65	0.78	0.92	1.07	1.22	1.39	1.57	1.76	1.97	2.18
9.00	0.50	0.61	0.73	0.85	0.99	1.14	1.29	1.46	1.64	1.82	2.02
10.00	0.47	0.57	0.68	0.80	0.93	1.07	1.21	1.37	1.54	1.71	1.90
15.00	0.39	0.47	0.56	0.66	0.77	0.88	1.00	1.13	1.27	1.41	1.56
20.00	0.35	0.43	0.51	0.60	0.69	0.80	0.91	1.02	1.15	1.28	1.42
25.00	0.33	0.40	0.48	0.56	0.65	0.75	0.85	0.96	1.08	1.21	1.34
30.00	0.32	0.39	0.46	0.54	0.63	0.72	0.82	0.93	1.04	1.16	1.29

Vs; Ship Speed (km/h) Ra; Area Ratio

Table 8-1-2 Drawdown versus Ship Size (Vs = 13 Km/h)

(Ra....Area Ratio) Unit: m

Ship Size \ Stage	First Stage	Second Stage	Master Plan
Ship (Max.)	0.84 (Ra = 4.0)	0.65 (Ra = 4.8)	0.65 (Ra = 4.8)
Ship (10,000 DWT)	0.20 (Ra = 11)	0.07 (Ra = 23)	0.05 (Ra = 30)

Ship (10,000 DWT) ..... 10,000 DWT class ship is of the highest frequency of transiting the Canal.

Ship (Max.) .... First Stage 60,000 DWT Tanker
Second Stage 150,000 DWT Tanker
Master Plan 250,000 DWT Tanker

1-2 Return Current

The mean velocity of return current Vr caused by a transiting ship is given by following equation:

$$Vr = Vs/(Ra-1) \tag{4}$$

The maximum velocity is about 2 times the value given by the above equation, and occurs near midships. The flow of current is outward at bow and inward at stern associated with eddies. Characteristics of the return current are shown in Table 8-1-1 and Fig. 8-1-2, and the velocities at each stage are shown in Table 8-1-3. The velocity, which depends largely on the area ratio, decreases from 1.2m/sec at pre-First Stage to about 1 m at post-First Stage for the maximum ship, while for 10,000 DWT class general cargo carrier, the velocity is very small at 0.4m/sec at pre-First Stage, 0.2 m/sec at the Second Stage and 0.1 m/sec at the Master Plan.

It has been pointed out that, since a return current flows associated with strong eddies, it is a main factor causing siltation in the Canal. Here, the velocity of current has been revealed to be less than that at pre-First Stage, and therefore a worsening in the siltation conditions caused by return current is not expected in the future plan.

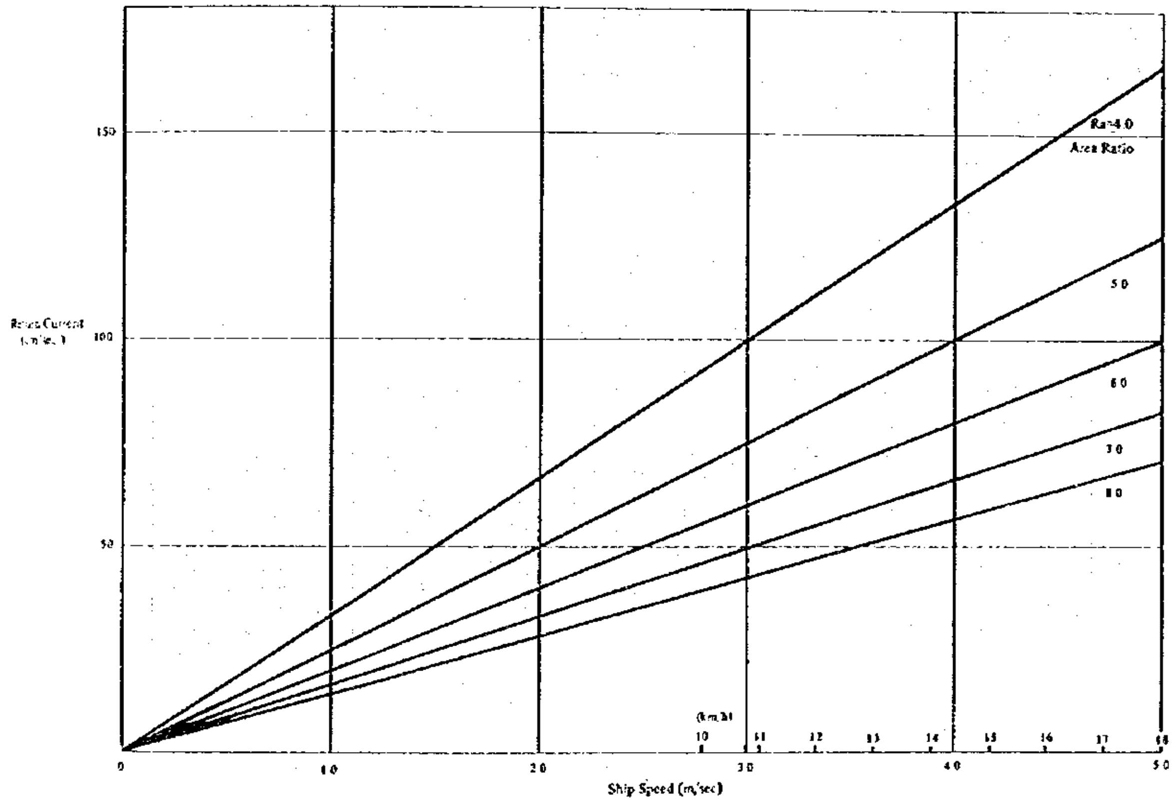


Fig. 8-1-2 Return Current

Table 8-1-3 Return Current (cm/sec)

Ship Size \ Stage	First Stage	Second Stage	Master Plan
Ship (Max.)	120	95	95
Ship (10,000 DWT)	36	17	13

1-3 Ship Wave

Ship wave, together with drawdown, causes a great influence on the stability of revetment. It is different from drawdown and return current, for it is dependent on ship speed and length, as given by the equation below:

$$Hs\ max = 0.73\ Vs^4/g^2 \cdot Ls = 0.00076\ Vs^4/LS \quad (5)$$

where, Hs max .... Max. ship wave height

Ls .... Ship length

As clearly seen in the equation above, the ship wave generated by a smaller ship with shorter length is greater. As a considerable increase of transit volume is forecasted for smaller size ships at the Second Stage and the Master Plan, a full account should be taken for maintenance of revetment. Ship wave characteristics are shown in Fig. 8-1-3 and Table 8-1-4.

Table 8-1-4 Ship Wave (m)

Vs \ Ls	10.000	20.000	30.000	40.000	50.000	100.000	150.000	200.000	250.000	300.000	350.000	400.000
10.000	0.045	0.023	0.015	0.011	0.009	0.005	0.003	0.002	0.002	0.002	0.001	0.001
11.000	0.255	0.033	0.022	0.017	0.013	0.007	0.004	0.003	0.003	0.002	0.002	0.002
12.000	0.094	0.047	0.031	0.023	0.019	0.009	0.006	0.005	0.004	0.003	0.003	0.002
13.000	0.129	0.065	0.043	0.032	0.026	0.013	0.009	0.006	0.005	0.004	0.004	0.003
14.000	0.174	0.087	0.058	0.043	0.035	0.017	0.012	0.009	0.007	0.006	0.005	0.004
15.000	0.229	0.115	0.076	0.057	0.046	0.023	0.015	0.011	0.009	0.008	0.007	0.006
16.000	0.297	0.148	0.099	0.074	0.059	0.030	0.020	0.015	0.012	0.010	0.008	0.007
17.000	0.378	0.189	0.126	0.094	0.076	0.038	0.025	0.019	0.015	0.013	0.011	0.009
18.000	0.475	0.238	0.158	0.119	0.095	0.048	0.032	0.024	0.019	0.016	0.014	0.012
19.000	0.590	0.295	0.197	0.147	0.118	0.059	0.039	0.029	0.024	0.020	0.017	0.015
20.000	0.724	0.362	0.241	0.181	0.145	0.072	0.048	0.036	0.029	0.024	0.021	0.018

Ls; Ship Length (m)   Vs; Ship Speed (km/h)

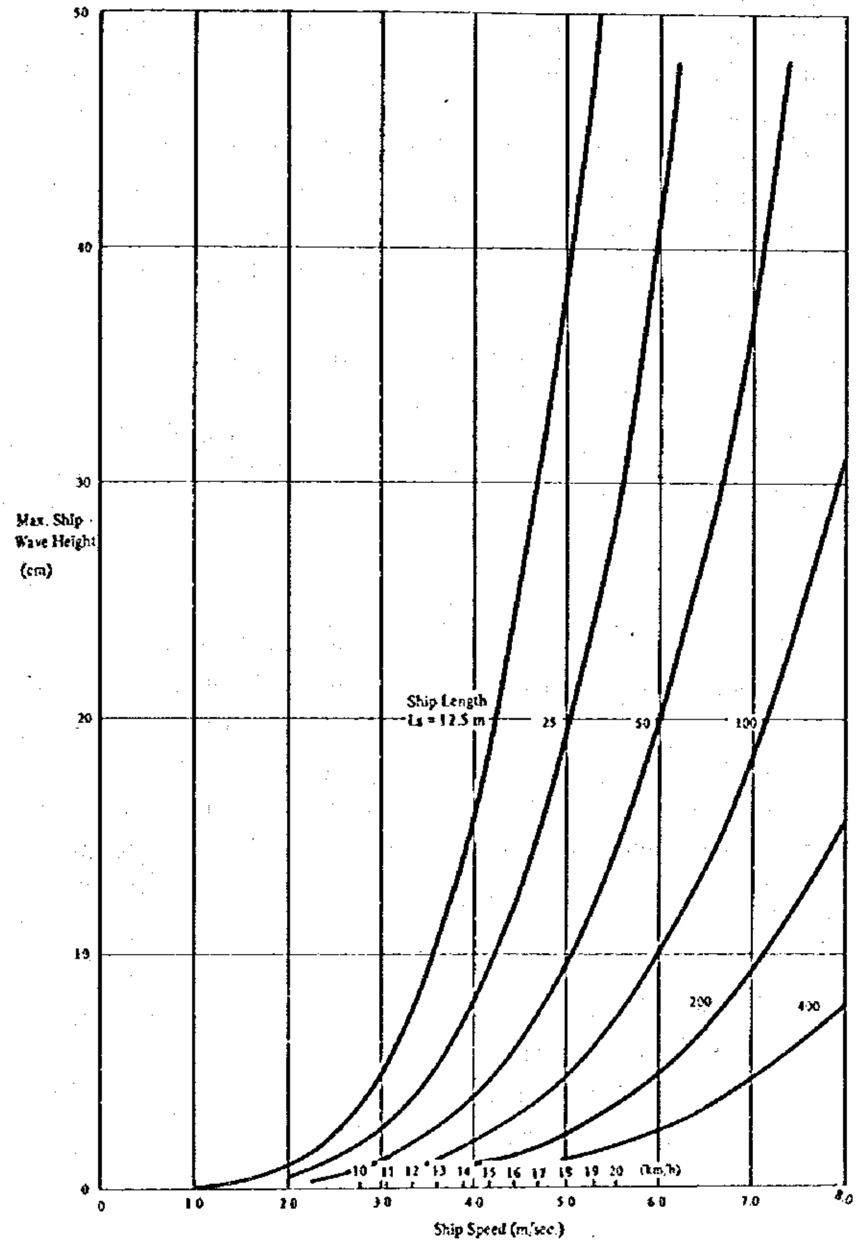


Fig. 8-1-3 Ship Wave

2. Canal Section

The dimensions of the Canal, which is called a restricted channel, are designed by taking into account the special conditions of restricted flow hydraulics. For the determining factors, i) characteristics of transit ships ii) natural conditions along the Canal and iii) maneuverability of ship and hydraulic phenomena due to ship's passage, can be given. Of the above, item iii) is of a completely different character from a channel in the open sea. A design method of the Canal has been established through past experiences and also through the results of detailed model studies. To summarize the procedure of designing, following steps are taken:

1) determine the maximum ship size
2) find the canal depth by adding an allowance to the draft of the ship
3) determine a channel width by lane ratio
4) if the area of the canal given above is of insufficient area ratio, then the canal is widened.

In step 4, an increased transiting resistance and ship induced hydraulic phenomena are considered.

2-1 Standard Ship Size

A ship's size is the most important factor in designing the Canal and therefore, before examining the Canal section, a brief review on ship size is given. Of ships transiting the Canal, a loaded tanker is the maximum size to determine the canal section, while general cargo carriers have the highest transit frequency to affect the stability of revertment, etc. Standard ship sizes of tankers and general cargo carriers are tabulated in Table 8-2-1. From the Table, the ship dimensions of draft, beam and length are expressed in relation to DWT by following equations. The characteristics of tanker dimensions are different between below 300,000 DWT and above, and given by different equations.

1) Tanker, 100,000 ~ 300,000 DWT

Full load draft $= -58.08 + 6.32 \ln DWT$ (m) (6)

Breadth $= -110.79 + 13.06 \ln DWT$ (7)

Length $= -729 + 86.34 \ln DWT$ (8)

2) Tanker 300,000 DWT ~

Full load draft $= -79.08 + 8.21 \ln DWT$ (9)

Breadth $= -205.34 + 20.41 \ln DWT$ (10)

Length $= -943.86 + 101.40 \ln DWT$ (11)

3) General Cargo Carrier

Full load draft $= 10.63 + 2.08 \ln DWT$ (12)

Breadth $= -26.96 + 5.10 \ln DWT$ (13)

Length $= -254.57 + 43.66 \ln DWT$ (14)

As the number of tankers over 300,000 DWT is very limited, the equations for them are not so reliable and therefore, the actual size of existing tankers should be used in designing the Canal. Ship sizes calculated are shown in Table 8-2-2.

Table 8-2-1 (a) Tanker Size (Japanese Standard)

DWT (t)	Length (m)	Breadth (m)	Draft (m)	B x D (m^2)
10,000	139	19.0	8.1	153.9
20,000	171	23.8	9.8	233.2
30,000	194	27.2	10.9	296.5
40,000	211	29.9	11.7	349.8
50,000	226	32.1	12.5	401.3
70,000	250	35.9	13.6	488.2
100,000	270	39.0	14.6	569.4
150,000	291	44.2	17.9	791.2
200,000	325	47.2	19.0	896.8
250,000	348	51.8	20.0	1103.6
332,000	345	53.3	24.8	1321.8
373,000	347	54.5	27.1	1477.0
484,000	379	62.0	28.2	1748.4

Table 8-2-1 (b) Tanker Size (by Sogreah's Report)

DWT (t)	Length (m)	Breadth (m)	Draft (m)
100,000		40	Laden 14.65
130,000		44	16.15
190,000		48	18.30
250,000		52	20.45
300,000		54	22.0
360,000		60	24.4
250,000	340	52	Ballast 11.40
330,000	350	55	12.80
400,000	370	60	13.0
550,000	400	64	16.5

Table 8-2-1 (c) Ship Size, General Cargo Carrier (Japanese Standard)

	DWT	Length (m)	Beam (m)	Depth (m)	Draft (m)
General Cargo Carrier	700	51	8.5	4.6	3.8
	1,000	58	9.5	5.1	4.2
	2,000	74	11.7	6.3	5.1
	3,000	86	13.2	7.2	5.9
	4,000	95	14.4	7.8	6.4
	5,000	103	15.4	8.4	6.8
	6,000	124	16.9	9.5	7.2
	7,000	129	17.6	10.0	7.5
	8,000	135	18.3	10.4	7.8
	9,000	139	18.9	10.8	8.0
	10,000	144	19.4	11.2	8.2
	15,000	162	21.7	12.7	9.1
	20,000	177	23.4	13.8	10.0
	30,000	199	26.1	15.7	11.0
	40,000	217	28.3	17.2	11.9
	50,000	232	30.0	18.4	12.7

Table 8-2-2 Ship Size Calculated

Tanker 100000~300000 DWT					Tanker 300000 DWT ~					General Cargo Carrier				
DWT	L (m)	D (m)	B (m)	D·B (m²)	DWT	L (m)	D (m)	B (m)	D·B (m²)	DWT	L (m)	D (m)	B (m)	D·B (m²)
100000.00	265.03	14.68	39.57	580.94	310000.00	339.27	24.73	52.73	1304.23	1000.	47.02	3.74	8.27	30.9
110000.00	273.26	15.28	40.81	623.80	320000.00	341.49	24.99	53.38	1333.97	2000.	77.29	5.18	11.90	61.15
120000.00	280.77	15.83	41.95	664.23	330000.00	344.61	25.24	54.01	1363.38	3000.	94.93	6.02	13.87	83.5
130000.00	287.68	16.34	43.00	702.54	340000.00	347.64	25.49	54.62	1392.07	4000.	107.55	6.62	15.34	101.5
140000.00	294.00	16.81	43.96	738.94	350000.00	350.58	25.73	55.21	1420.29	5000.	117.29	7.09	16.49	116.7
150000.00	300.03	17.24	44.86	773.65	360000.00	353.44	25.96	55.78	1447.98	6000.	125.25	7.46	17.41	129.9
160000.00	305.61	17.65	45.71	806.83	370000.00	356.22	26.18	56.34	1475.17	7000.	131.98	7.79	18.13	141.5
170000.00	310.84	18.04	46.50	839.02	380000.00	358.92	26.40	56.89	1501.89	8000.	137.91	8.06	18.87	152.1
180000.00	315.78	18.40	47.25	869.15	390000.00	361.55	26.61	57.42	1528.12	9000.	142.95	8.31	19.49	161.8
190000.00	320.44	18.74	47.95	898.52	400000.00	364.12	26.82	57.93	1553.92	10000.	147.55	8.53	20.01	170.6
200000.00	324.87	19.06	48.62	926.84	410000.00	366.62	27.03	58.44	1579.28	15000.	165.26	9.37	22.00	205.9
210000.00	329.06	19.37	49.26	954.17	420000.00	369.07	27.22	58.93	1604.23	20000.	177.82	9.97	23.55	234.7
220000.00	333.10	19.66	49.87	980.60	430000.00	371.45	27.42	59.41	1628.78	25000.	187.56	10.43	24.59	257.5
230000.00	336.94	19.95	50.45	1006.19	440000.00	373.79	27.61	59.88	1652.95	30000.	195.52	10.81	25.62	276.9
240000.00	340.61	20.21	51.00	1031.00	450000.00	376.06	27.79	60.34	1676.74	35000.	202.25	11.13	26.40	293.9
250000.00	344.14	20.47	51.54	1055.07	460000.00	378.29	27.97	60.79	1700.18	40000.	208.00	11.41	27.00	305.8
260000.00	347.52	20.72	52.05	1078.46	470000.00	380.47	28.15	61.22	1723.26	45000.	213.22	11.66	27.69	322.6
270000.00	350.78	20.96	52.54	1101.20	480000.00	382.61	28.32	61.65	1746.02	50000.	217.82	11.88	28.22	335.
280000.00	353.92	21.19	53.02	1123.34	490000.00	384.70	28.49	62.08	1768.44					
290000.00	356.95	21.41	53.47	1144.91	500000.00	386.75	28.65	62.49	1790.55					
300000.00	359.88	21.62	53.92	1165.94										

L; Ship Length (m), D; Draft (m), B; Beam (m)

2-2 Required canal depth

The required canal depth (dredging depth) is the total of loaded draft, squat, trim, and allowance, with a depth decrease due to siltation considered.

2-2-1 Full load draft

The full load draft should be for the largest ship which is anticipated to transit the Canal, and can be taken from Table 8-2-2 or can be an approximated value from the existing ships. For a general consideration, the value in Table B-2-2 will be used.

2-2-2 Squat and trim

Duing navigating a ship sinks down, and the average hull sinkage is called "Squat", and a difference in draft between the stern and the bow is called "Trim". Both of them are given as a function of Froude Number, and from experimental results these are expressed by the following equations:

$$\text{Squat} = (1.43\ Vs/\sqrt{gh} - 0.11)L_{PP}/100 \quad (15)$$

$$\text{Trim} = (0.57\ Vs/\sqrt{gh} - 0.03)L_{PP}/100 \quad (16)$$

where, h .... canal depth

L_{PP} ..... length perpendicular

The equations above have been derived by taking the maximum value of experiment, and thus give somewhat conservative values of squat and trim.

2-2-3 Allowance

In addition to the above, for a higher efficiency of propellar thrust and a temporary increase of draft, an allowance is added. The allowance is usually taken as 5% of the ship's draft.

$$\text{Allowance} = 0.05 \times \text{Full load draft} \quad (17)$$

2-2-4 Depth decrease due to siltation

The canal depth gradually decreases due to siltation caused by a return current and a tidal flow. Therefore, "a mean effective depth" for a transit ship is less than an initial dredging depth by a thickness of deposition. When a maintenance dredging is frequently carried out, a volume of siltation becomes less and the initial dredging depth can be decreased. However, this inhibits the smooth transit of vessels. Here, considering the efficiency of dredging, it is assumed that maintenance dredging is to be carried out periodically when a thickness average at 50 cm. The maximum thickness is assumed to be double the average to give 1.0 m, in consideration of local variation.

In total, the initial dredging depth is given as a summation of full load draft, squat, half the trim, the allowance, and 1.0 m for siltation.

For a 100,000 – 300,000 DWT class tanker, the channel depth is given as below:

$$\text{Dredging Depth} = 1.05\,(-58.08 + 6.32\ \ln \text{DWT}) + (1.72\ Vs/\sqrt{gh} - 0.13)^{L}PP/100 + 1.00\ (m) \qquad (18)$$

The dredging depth is determined by ship size and speed, as shown in Table 8-2-3.

An effective canal depth for transit ships is reduced to the dredging depth minus 25 cm, which is an average depth of siltation over the interval of maintenance dredging.

2-3 Lane width

The width of navigation lane is determined by considering the navigation accuracy of the ship, the natural conditions along the Canal, the bank suction, etc. The positioning accuracy of a ship is usually taken as ±0.5 B (B... ship's breadth) to give a total lane width of 2B. In addition to this, in the case of a restricted channel, a clearance is secured against a suction force toward a bank. When the maximum, rudder angle is taken as less than 15°, the clearance should be more than about 0.5B, to give a total lane width of 3B. This is only an approximate index for the required width of a restricted channel.

The lane width of the Canal has been determined based on the extensive past experiences and results of experimental studies. In this Study, following values are taken, according to the values presently adopted.

	Lane Ratio
Laden Tanker	2.6
Ballast Tanker	2.7

The ratio for a laden tanker is the same as a present one, but for a ballast tanker the ratio of 2.7 is adopted. The team has been informed by experienced shipping companies that a minimum draft of 12m is necessary for the control of a VLCC and this has been adopted in this Study. The above ratio of 2.7 for a draft of 12m is slightly larger than 2.8 for a draft of 11m.

2-4 Cross Sectional Area

A canal section may be designed, based on the values obtained up to the previous section, by taking a bank slope of 1/4 for a northern reach and 1/3 for a southern portion. However, differing from a channel in the open sea, it is necessary to take into account an "Area Ratio" which is a controlling factor to the resistance of a navigating ship and the siltation rate in the channel. An extensive study has been made of the area ratio which should be taken to accommodate a VLCC, examining the relationship of engine power, ship speed, cavitation, and siltation in the canal. As a conclusion, a larger value is recommended for use with VLCCs. According to the present values taken, the followings are adopted in this Study.

In the case of a laden tanker, it is indispensable to increase the area ratio considerably to allow a VLCC to transit at a speed higher than 13 km/h, and cavitation is expected since the engine power of VLCC is relatively small in relation to the size of the hull. Therefore, the allowable speed limit of 13 km/h for an area ratio of 4.8 is judged to be reasonable. For a ballast tanker, a resistance is not so serious as a laden one, since a clearance between keel and canal bed

Table 8-2-3 Canal Depth Required (m) (Laden Tanker)

Canal Depth \ DWT	100000.00	110000.00	120000.00	130000.00	140000.00	150000.00	160000.00	170000.00	180000.00
Ship Speed 10 km/h									
Draft	14.68	15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
Squat	0.51	0.52	0.52	0.52	0.52	0.52	0.53	0.53	0.53
Trim	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13
0.05 x Draft	0.73	0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	17.05	17.69	18.27	18.80	19.30	19.76	20.16	20.59	20.97
Ship Speed 11 km/h									
Draft	14.68	15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
Squat	0.59	0.60	0.60	0.61	0.61	0.61	0.61	0.61	0.61
Trim	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
0.05 x Draft	0.73	0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	17.15	17.79	18.37	18.90	19.40	19.86	20.29	20.69	21.07
Ship Speed 12 km/h									
Draft	14.68	15.28	15.83	16.34	16.61	17.24	17.65	18.04	18.40
Squat	0.68	0.68	0.69	0.69	0.69	0.69	0.70	0.70	0.70
Trim	0.15	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.16
0.05 x Draft	0.73	0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	17.24	17.88	18.47	19.00	19.50	19.96	20.39	20.80	21.18
Ship Speed 13 km/h									
Draft	14.68	15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
Squat	0.76	0.76	0.77	0.77	0.78	0.78	0.78	0.78	0.79
Trim	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.18	0.18
0.05 x Draft	0.73	0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	17.34	17.98	18.57	19.10	19.60	20.06	20.49	20.90	21.28
Ship Speed 14 km/h									
Draft	14.68	15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
Squat	0.84	0.84	0.85	0.86	0.86	0.86	0.87	0.87	0.87
Trim	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.20	0.20
0.05 x Draft	0.73	0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	17.44	18.08	18.67	19.20	19.70	20.16	20.60	21.00	21.39
Ship Speed 15 km/h									
Draft	14.68	15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
Squat	0.92	0.93	0.93	0.94	0.95	0.95	0.95	0.96	0.96
Trim	0.20	0.20	0.21	0.21	0.21	0.21	0.21	0.21	0.21
0.05 x Draft	0.73	0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	17.53	18.18	18.77	19.30	19.80	20.27	20.70	21.11	21.49
Ship Speed 16 km/h									
Draft	14.68	15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
Squat	1.00	1.01	1.02	1.02	1.03	1.04	1.04	1.04	1.05
Trim	0.22	0.22	0.22	0.22	0.23	0.23	0.23	0.23	0.23
0.05 x Draft	0.73	0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	17.63	18.28	18.86	19.40	19.90	20.37	20.80	21.21	21.59
Ship Speed 17 km/h									
Draft	14.68	15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
Squat	1.08	1.09	1.10	1.11	1.11	1.12	1.13	1.13	1.13
Trim	0.23	0.24	0.24	0.24	0.25	0.24	0.25	0.25	0.25
0.05 x Draft	0.73	0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	17.73	18.37	18.96	19.51	20.01	20.47	20.91	21.31	21.70
Ship Speed 18 km/h									
Draft	14.68	15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
Squat	1.16	1.17	1.18	1.19	1.20	1.21	1.21	1.22	1.22
Trim	0.25	0.25	0.26	0.26	0.26	0.26	0.26	0.26	0.27
0.05 x Draft	0.73	0.75	0.79	0.82	0.84	0.86	0.88	0.90	0.92
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	17.82	18.47	19.06	19.61	20.11	20.57	21.01	21.42	21.80
Ship Speed 19 km/h									
Draft	14.68	15.28	15.83	16.34	16.61	17.24	17.65	18.04	18.40
Squat	1.24	1.25	1.27	1.28	1.28	1.29	1.30	1.30	1.31
Trim	0.27	0.27	0.27	0.27	0.28	0.28	0.28	0.28	0.28
0.05 x Draft	0.73	0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	17.92	18.57	19.16	19.71	20.21	20.68	21.11	21.52	21.91
Ship Speed 20 km/h									
Draft	14.68	15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
Squat	1.32	1.34	1.35	1.36	1.37	1.38	1.38	1.39	1.40
Trim	0.28	0.29	0.29	0.29	0.29	0.30	0.30	0.30	0.30
0.05 x Draft	0.73	0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	18.02	18.67	19.26	19.81	20.31	20.78	21.22	21.63	22.01

0.05 x Draft; Keel Clearance, Siltation; Allowance for Siltation

Table 8-2-3 Canal Depth Required (m) (Laden Tanker)

…0000.00	120000.00	130000.00	140000.00	150000.00	160000.00	170000.00	180000.00
15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
0.52	0.52	0.52	0.52	0.52	0.53	0.52	0.52
0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13
0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
17.69	18.27	18.80	19.30	19.76	20.16	20.59	20.97
15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
0.60	0.60	0.61	0.61	0.61	0.61	0.61	0.61
0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
17.79	18.37	18.90	19.40	19.86	20.29	20.69	21.07
15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
0.68	0.69	0.69	0.69	0.69	0.70	0.70	0.70
0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.16
0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
17.88	18.47	19.00	19.50	19.96	20.39	20.80	21.18
15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
0.76	0.77	0.77	0.78	0.78	0.78	0.78	0.79
0.17	0.17	0.17	0.18	0.18	0.18	0.18	0.18
0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
17.98	18.57	19.10	19.60	20.06	20.49	20.90	21.28
15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
0.84	0.85	0.86	0.86	0.86	0.87	0.87	0.87
0.19	0.19	0.19	0.19	0.19	0.19	0.20	0.20
0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
18.08	18.67	19.20	19.70	20.16	20.60	21.00	21.39
15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
0.93	0.93	0.94	0.95	0.95	0.95	0.96	0.96
0.20	0.21	0.21	0.21	0.21	0.21	0.21	0.21
0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
18.18	18.77	19.30	19.80	20.27	20.70	21.11	21.49
15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
1.01	1.02	1.02	1.03	1.04	1.04	1.04	1.05
0.22	0.22	0.22	0.23	0.23	0.23	0.23	0.23
0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
18.28	18.86	19.40	19.92	20.37	20.80	21.21	21.59
15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
1.09	1.10	1.11	1.11	1.12	1.13	1.13	1.13
0.24	0.24	0.24	0.24	0.24	0.25	0.25	0.25
0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
18.37	18.96	19.51	20.01	20.47	20.91	21.31	21.70
15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
1.17	1.18	1.19	1.20	1.21	1.21	1.22	1.22
0.25	0.26	0.26	0.26	0.26	0.26	0.26	0.27
0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
18.47	19.06	19.61	20.11	20.57	21.01	21.42	21.80
15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
1.25	1.27	1.28	1.28	1.29	1.30	1.30	1.31
0.27	0.27	0.27	0.28	0.28	0.28	0.28	0.28
0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
18.57	19.16	19.71	20.21	20.68	21.11	21.52	21.91
15.28	15.83	16.34	16.81	17.24	17.65	18.04	18.40
1.34	1.35	1.36	1.37	1.39	1.38	1.39	1.40
0.29	0.29	0.29	0.29	0.30	0.30	0.30	0.30
0.76	0.79	0.82	0.84	0.86	0.88	0.90	0.92
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
18.67	19.26	19.81	20.31	20.78	21.22	21.63	22.01

…on; Allowance for Siltation

Table 8-2-3 Canal Depth Required (cont'd)

DWT	190000.00	200000.00	210000.00	220000.00	230000.00	240000.00	250000.00	260000.00	270000.00	280000.00	290000.00	300000.00
Ship Speed 10 km/h												
Draft	18.74	19.06	19.37	19.66	19.95	20.21	20.47	20.72	20.96	21.19	21.41	21.62
Squat	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52
Trim	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
0.05 x Draft	0.94	0.95	0.97	0.98	1.00	1.01	1.02	1.04	1.05	1.06	1.07	1.08
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	21.33	21.67	21.99	22.30	22.59	22.87	23.15	23.41	23.66	23.90	24.13	24.35
Ship Speed 11 km/h												
Draft	18.74	19.06	19.37	19.66	19.95	20.21	20.47	20.72	20.96	21.19	21.41	21.62
Squat	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
Trim	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
0.05 x Draft	0.94	0.95	0.97	0.98	1.00	1.01	1.02	1.04	1.05	1.06	1.07	1.08
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	21.43	21.77	22.10	22.41	22.70	22.98	23.25	23.51	23.76	24.00	24.24	24.46
Ship Speed 12 km/h												
Draft	18.74	19.06	19.37	19.66	19.95	20.21	20.47	20.72	20.96	21.19	21.41	21.62
Squat	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Trim	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
0.05 x Draft	0.94	0.95	0.97	0.98	1.00	1.01	1.02	1.04	1.05	1.06	1.07	1.08
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	21.54	21.88	22.20	22.51	22.81	23.09	23.36	23.62	23.87	24.11	24.35	24.57
Ship Speed 13 km/h												
Draft	18.74	19.06	19.37	19.66	19.95	20.21	20.47	20.72	20.96	21.19	21.41	21.62
Squat	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
Trim	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
0.05 x Draft	0.94	0.95	0.97	0.98	1.00	1.01	1.02	1.04	1.05	1.06	1.07	1.08
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	21.64	21.93	22.31	22.62	22.92	23.20	23.47	23.73	23.98	24.22	24.46	24.69
Ship Speed 14 km/h												
Draft	18.74	19.06	19.37	19.66	19.95	20.21	20.47	20.72	20.96	21.19	21.41	21.62
Squat	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Trim	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
0.05 x Draft	0.94	0.95	0.97	0.98	1.00	1.01	1.02	1.04	1.05	1.06	1.07	1.08
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	21.75	22.09	22.42	22.73	23.02	23.31	23.58	23.84	24.09	24.33	24.57	24.79
Ship Speed 15 km/h												
Draft	18.74	19.06	19.37	19.66	19.95	20.21	20.47	20.72	20.96	21.19	21.41	21.62
Squat	0.96	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Trim	0.21	0.21	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
0.05 x Draft	0.94	0.95	0.97	0.98	1.00	1.01	1.02	1.04	1.05	1.06	1.07	1.08
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	21.85	22.20	22.52	22.83	23.13	23.41	23.69	23.95	24.20	24.44	24.67	24.90
Ship Speed 16 km/h												
Draft	18.74	19.06	19.37	19.66	19.95	20.21	20.47	20.72	20.96	21.19	21.41	21.62
Squat	1.05	1.05	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.07	1.07
Trim	0.23	0.23	0.23	0.23	0.23	0.23	0.24	0.24	0.24	0.24	0.24	0.24
0.05 x Draft	0.94	0.95	0.97	0.98	1.00	1.01	1.02	1.04	1.05	1.06	1.07	1.08
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	21.96	22.30	22.63	22.94	23.24	23.52	23.79	24.06	24.31	24.55	24.78	25.01
Ship Speed 17 km/h												
Draft	18.74	19.06	19.37	19.66	19.95	20.21	20.47	20.72	20.96	21.19	21.41	21.62
Squat	1.14	1.14	1.14	1.15	1.15	1.15	1.15	1.15	1.15	1.16	1.16	1.16
Trim	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.26	0.26
0.05 x Draft	0.94	0.95	0.97	0.98	1.00	1.01	1.02	1.04	1.05	1.06	1.07	1.08
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	22.05	22.41	22.73	23.05	23.34	23.63	23.90	24.16	24.42	24.66	24.89	25.12
Ship Speed 18 km/h												
Draft	18.74	19.06	19.37	19.66	19.95	20.21	20.47	20.72	20.96	21.19	21.41	21.62
Squat	1.23	1.23	1.23	1.24	1.24	1.24	1.24	1.24	1.25	1.25	1.25	1.25
Trim	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
0.05 x Draft	0.94	0.95	0.97	0.98	1.00	1.01	1.02	1.04	1.05	1.06	1.07	1.08
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	22.17	22.51	22.84	23.15	23.45	23.74	24.01	24.27	24.52	24.77	25.00	25.23
Ship Speed 19 km/h												
Draft	18.74	19.06	19.37	19.66	19.95	20.21	20.47	20.72	20.96	21.19	21.41	21.62
Squat	1.31	1.32	1.32	1.32	1.33	1.33	1.33	1.33	1.34	1.34	1.34	1.34
Trim	0.28	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
0.05 x Draft	0.94	0.95	0.97	0.98	1.00	1.01	1.02	1.04	1.05	1.06	1.07	1.08
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	22.27	22.62	22.95	23.26	23.56	23.84	24.12	24.38	24.63	24.88	25.11	25.34
Ship Speed 20 km/h												
Draft	18.74	19.06	19.37	19.66	19.95	20.21	20.47	20.72	20.96	21.19	21.41	21.62
Squat	1.40	1.41	1.41	1.41	1.42	1.42	1.42	1.42	1.43	1.43	1.43	1.43
Trim	0.30	0.30	0.30	0.30	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
0.05 x Draft	0.94	0.95	0.97	0.98	1.00	1.01	1.02	1.04	1.05	1.06	1.07	1.08
Siltation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	22.38	22.72	23.05	23.37	23.67	23.95	24.23	24.49	24.74	24.99	25.22	25.45

0.05 x Draft; Keel Clearance, Siltation; Allowance for Siltation

is greater. However, to take a small area ratio is to give rise to a high return current, and will increase the siltation rate considerably. Thus, in this Study, the above value of 4.6 is adopted for a ship speed of 14 km/h in the case of a ballast tanker. A total effective cross sectional area, which is calculated by using an effective canal depth (mentioned in 2-2-4), should not be less than the value of area ratio x B x D. (B: breadth D: draft).

Canal dimensions for a laden tanker are calculated according to the above method and listed in Table 8-2-4. As seen in the table:

a) the canal section determined by lane ratio gives insufficient area ratio; 4.3 for bank slope 1/3, 4.7 for bank slope 1/4,

b) hence, the canal section is determined by area ratio to give an increased lane ratio; 3.1 for bank slope 1/3, 2.7 for 1/4.

Table 8-2-4 Canal Dimension Calculated

Bank Slop 1/4

DWT	100000.00	110000.00	120000.00	130000.00	140000.00	150000.00	160000.00	170000.00	180000.00	190000.00	
Canal Depth	17.34	17.99	18.57	19.11	19.60	20.07	20.50	20.90	21.28	21.65	
Keel Level	15.61	16.22	16.78	17.29	17.76	18.20	18.61	19.00	19.36	19.71	
Area Required	2789.58	2994.22	3188.32	3372.17	3546.92	3713.51	3872.76	4025.37	4171.91	4312.91	
Width Required	102.88	106.12	109.07	111.79	114.30	116.65	118.84	120.90	122.84	124.67	
Section calculated by lane ratio											
Surface Width	227.76	235.08	243.29	250.11	256.41	262.27	267.76	272.90	277.75	282.34	
−11m Width	139.76	147.09	155.29	162.11	168.41	174.27	179.76	184.90	189.75	194.34	
Bed Width	89.01	92.08	94.74	97.25	99.58	101.75	103.78	105.69	107.49	109.18	
Area	2747.08	2940.54	3130.58	3318.47	3499.35	3652.10	3807.74	3956.74	4099.75	4237.29	
Lane Ratio	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	
Area Ratio	4.73	4.73	4.73	4.72	4.72	4.72	4.72	4.72	4.72	4.72	
Section calculated by area ratio											
Surface Width	231.50	239.77	247.32	254.26	260.68	266.67	272.26	277.52	282.47	287.16	
−11m Width	143.50	151.77	159.32	166.26	172.68	178.67	184.26	189.52	194.47	199.16	
Bed Width	92.75	95.89	98.76	101.40	103.85	105.14	108.28	110.30	112.20	114.00	
Area	2911.93	3010.44	3213.26	3397.77	3571.13	3740.30	3920.03	4053.19	4200.21	4341.66	
Lane Ratio	2.69	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	
Area Ratio	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	
DWT	200000.00	210000.00	220000.00	230000.00	240000.00	250000.00	260000.00	270000.00	280000.00	290000.00	300000.00
Canal Depth	21.99	22.31	22.62	22.92	23.20	23.47	23.73	23.99	24.23	24.46	24.68
Keel Level	20.03	20.34	20.64	20.92	21.19	21.45	21.70	21.94	22.17	22.39	22.60
Area Required	4448.82	4580.03	4706.89	4829.72	4948.78	5064.23	5176.59	5285.77	5392.04	5495.56	5596.53
Width Required	126.42	128.07	129.65	131.16	132.61	133.99	135.32	136.61	137.84	139.02	140.19
Section calculated by lane ratio											
Surface Width	286.69	290.93	294.77	298.53	302.14	305.59	308.91	312.10	315.19	318.15	321.01
−11m Width	198.69	202.63	206.77	210.53	214.14	217.59	220.91	224.10	227.18	230.15	233.01
Bed Width	110.79	112.32	113.79	115.18	116.52	117.80	119.04	120.22	121.37	122.47	123.53
Area	4369.81	4497.69	4621.29	4740.98	4856.82	4969.27	5078.49	5184.67	5287.99	5388.63	5486.72
Lane Ratio	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
Area Ratio	4.71	4.71	4.71	4.71	4.71	4.71	4.71	4.71	4.71	4.71	4.71
Section calculated by area ratio											
Surface Width	291.61	295.84	299.88	303.73	307.42	310.96	314.37	317.64	320.79	323.84	326.79
−11m Width	203.61	207.84	211.88	215.73	219.42	222.96	226.37	229.64	232.79	235.84	238.78
Bed Width	115.71	117.34	118.89	120.38	121.81	123.18	124.49	125.76	126.98	128.15	129.30
Area	4478.08	4609.62	4736.87	4860.06	4979.48	5095.38	5207.97	5317.46	5424.04	5527.87	5629.11
Lane Ratio	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.71	2.71	2.71	2.71
Area Ratio	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80

Table 8-2-4 Canal Dimension Calculated (cont'd)

Bank Slope 1/3

DWT	100000.00	110000.00	120000.00	130000.00	140000.00	150000.00	160000.00	170000.00	180000.00	190000.00
Canal Depth	17.24	17.99	18.57	19.11	19.60	20.07	20.52	20.98	21.29	21.65
Keel Level	15.61	15.22	16.79	17.29	17.76	18.20	18.61	19.00	19.36	19.71
Area Required	2788.58	2994.22	3188.32	3372.17	3546.92	3713.51	3872.76	4025.37	4171.91	4312.91
Width Required	102.88	106.12	109.07	111.79	114.30	116.65	118.84	120.98	122.84	124.67
Section calculated by lane ratio										
Surface Width	195.54	203.44	209.74	215.53	220.86	225.87	230.53	234.98	239.03	242.92
−11m Width	130.54	137.44	143.74	149.53	154.86	159.87	164.53	168.98	173.03	176.92
Bed Width	92.47	95.53	98.32	100.89	103.26	105.47	107.54	109.49	111.32	113.05
Area	2506.33	2688.53	2860.28	3022.03	3177.21	3324.28	3461.70	3599.32	3728.45	3852.62
Lane Ratio	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
Area Ratio	4.31	4.31	4.31	4.30	4.30	4.30	4.29	4.29	4.29	4.29
Section calculated by area ratio										
Surface Width	214.41	222.03	229.00	235.40	241.33	246.85	252.01	256.87	261.41	265.77
−11m Width	148.41	156.03	163.00	169.40	175.33	180.85	186.01	190.87	195.41	199.77
Bed Width	110.34	114.12	117.58	120.76	123.71	126.46	129.03	131.45	133.72	135.90
Area	2816.27	3022.94	3217.90	3402.55	3578.03	3745.71	3905.21	4058.42	4205.53	4347.07
Lane Ratio	3.05	3.06	3.05	3.06	3.07	3.07	3.07	3.07	3.07	3.08
Area Ratio	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80

DWT	200000.00	210000.00	220000.00	230000.00	240000.00	250000.00	260000.00	270000.00	280000.00	290000.00	300000.00
Canal Depth	21.99	22.31	22.62	22.92	23.20	23.47	23.73	23.99	24.23	24.46	24.68
Keel Level	20.03	20.34	20.64	20.92	21.19	21.45	21.70	21.94	22.17	22.39	22.60
Area Required	4443.82	4580.03	4706.89	4829.72	4943.73	5054.33	5176.59	5285.77	5392.24	5495.58	5596.57
Width Required	126.42	128.07	129.65	131.16	132.61	133.99	135.32	136.61	137.84	139.03	140.18
Section calculated by lane ratio											
Surface Width	246.62	250.14	253.49	256.69	259.75	262.69	265.51	268.23	270.84	273.37	275.80
−11m Width	180.62	184.14	187.49	190.69	193.75	196.69	199.51	202.23	204.84	207.37	209.80
Bed Width	114.70	116.26	117.75	119.18	120.54	121.85	123.11	124.32	125.48	126.61	127.70
Area	3972.25	4087.69	4199.23	4307.15	4411.79	4513.27	4611.82	4707.63	4800.85	4891.64	4980.14
Lane Ratio	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
Area Ratio	4.29	4.28	4.28	4.28	4.28	4.28	4.28	4.27	4.27	4.27	4.27
Section calculated by area ratio											
Surface Width	269.87	273.78	277.58	281.06	284.47	287.74	290.85	293.90	296.82	299.63	302.34
−11m Width	203.87	207.78	211.58	215.06	218.47	221.74	224.89	227.90	230.82	233.63	236.34
Bed Width	137.95	139.90	141.77	143.55	145.26	146.90	148.49	149.99	151.45	152.87	154.24
Area	4493.58	4615.20	4742.52	4865.79	4985.20	5101.25	5213.90	5323.45	5429.63	5533.93	5635.28
Lane Ratio	3.08	3.08	3.08	3.09	3.08	3.09	3.09	3.09	3.09	3.09	3.09
Area Ratio	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80

3. Tidal Current and Water Level in the Canal

The resistance to tidal current decreases with the larger cross sectional area of an enlarged canal resulting in increased velocity of current. The increased velocity affects the maneuverability of ship and siltation in the Canal, while the change of water level affects the dredging datum level. For the above points, a detailed analysis has been made by numerical calculation. Here, the characteristics of the tidal current for the proposed canal in the Second Stage and the Master Plan will be examined by a similar method, and the effects on the Canal will be discussed.

3-1 Water level

As the datum for the tidal level, the marker stone installed in Suez when Lesseps constructed the Canal, representing a level 20m below mean sea level, has been traditionally used.

According to the record of tidal levels at Port Said and Port Tewfik situated at the ends of the Canal, the tidal range is as large as 0.4m at Port Said and 2.0m at Port Tewfik, shown in Table 8-3-1. The highest tide is called a storm tide, which includes the effect of atmospheric depression and wind setup.

The mean sea level is generally higher in the Red Sea than in the Mediterranean Sea so that as a whole, a northward residual current is produced and a current due to tidal fluctuations is superposed.

H.W.L. and L.W.L. at points along the Canal are represented in Table 8-3-1. The velocity of the tidal current is higher in the reach between the Little Bitter Lake and Suez, and diminishes in the Great Bitter Lake. The tidal current flows at the maximum velocity of 30cm/sec in the northern part of the Great Bitter Lake, 40cm/sec at Port Said and 150cm/sec (mean velocity at 100cm/sec) at Suez.

Table – 8-3-1 (a) Tidal Level

Unit: m

	Port Said	Port Tewfik
H.H.W.L	18,60	19.50
L.L.W.L	17.40	17.00
H.W.L	18.49	19.00
L.W.L	18.09	17.50

Table – 8-3-1 (b) Mean Tidal Level (monthly)

Unit: m

	Port Said	Port Tewfik		Port Said	Port Tewfik
Jan.	18,013	<18,355	July	18,115	<18,169
Feb.	17,993	<18,351	Aug.	18,146	>18,144
Mar.	17,953	<18,313	Sept.	18,120	>18,097
Apr.	17,956	<18,319	Oct.	18,085	<18,197
May	17,979	<18,309	Nov.	18,086	<18,391
Jun.	18,036	<18,211	Dec.	18,076	<18,407