Table – 8-3-1 (c) Tidal Level along the Canal

Unit: m

	H.W.L	L.W.L	Remark
Port Said	18.49	18.09	
Roz El Ech	18.45	18.11	15 Km
34 Km	18.39	18.14	
El Ferdan	18.33	18.22	65 Km
Ismailia	18.30	18.26	Timsah Lake
Deversoir	18.27	18.25	Great Bitter Lake, 97 Km
133 Km	18.30	18.20	Little Bitter Lake
Chalouf	18.43	18.07	146 Km
Port Tewfik	19.00	17.50	

3-2 Analysis of tidal current

The tidal current and level along the Canal at each stage of development of the Canal have been analyzed by numerical calculation. The Canal sections taken are those after completion of the First and Second Stages and of the Master Plan. The Canal in the Second Stage and the Master Plan is completely doubled. The method of calculation is the same as that employed by Maunsell Consultants Ltd., but the initial conditions of calculation are more or less different. The results described here, without much calculation, are not applicable quantitatively to the site, and further detailed calculations are required to quantify the future characteristics of the tide in the Canal.

(1) Conditions of Calculation

The method of calculation is almost the same as that used by Maunsell Consultants Ltd. Thus, only the initial conditions will be described here.

1) Tidal level

Tidal levels were given as boundary conditions at both ends of the Canal. The elements of the tide are shown in Table 8-3-2. The mean tidal levels were taken as M.T.L. ±0.0m at Port Said and M.T.L. -0.20m at Suez.

The calculation started at 19h, 9th day, September 1976, and ending at 5h, 20th day, September 1976, and tidal level, current velocity, discharge were listed out at one hour intervals.

2) Canal profile

For the section of single channel, the actual dimensions were used. For the reach of doubled channels, two canal sections were converted into a single trapezoid, such that its cross-sectional area and transversal extension on still water level may be equal to the sum of those of two channels (Fig. 8-3-1). For the canal depth, a greater depth was taken near and at the each end, considering a difference of the working datum along the Canal. Dimensions of the Canal used in the calculation are listed in Table 8-3-3 (Cross-section in the Second Stage corresponding to Plan-5)

For the other calculating conditions such as wind stress, salinity, etc., the values of Maunsell Consultants Ltd. were followed.

Table – 8-3-2 Harmonics

	Frequency (°/h)	Phase (°)	Amplitude (m)	
O_1	13.943	198.0	0.013	Suez
K_1	15.041	184.0	0.045	
N_2	28.440	305.0	0.182	
M_2	28.984	336.0	0.560	
S_2	30.000	4.0	0.141	
M_4	57.968	112.0	0.009	
O_1	13.943	273.0	0.02	Port Said
K_1	15.041	303.0	0.02	
N_2	28.440	298.0	0.02	
M_2	28.984	298.0	0.12	
S_2	30.000	314.0	0.07	

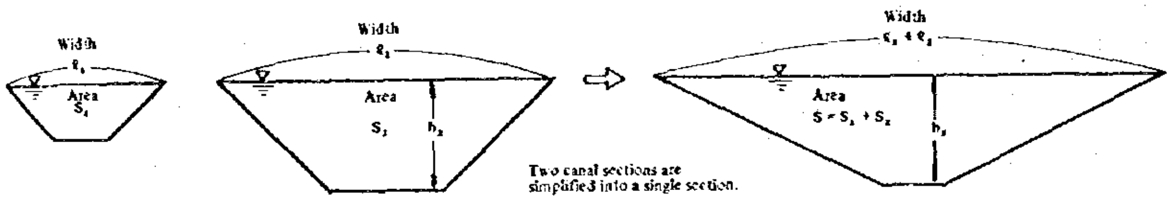


Fig. 8-3-1 Canal Cross Section for Tide Analysis

Table 8-3-3 (a) Suez Canal Dimension (Width at −11 m) (after First Stage)

Point	km	East Channel			West Channel			Total Area (m^2)	Simplified Canal Section			
		Depth (m)	Width (m)	Area (m^2)	Depth (m)	Width (m)	Area (m^2)		Surface Width (m)	Bed Width (m)	Bank Slope	Depth (m) (below M.S.L.)
	0.0	19.5	170	3,510	15.5	170	3,038	6,548	516	156	9.23	20.4
	5.0	19.5	170	3,510	15.5	170	3,038	6,548	516	156	9.23	20.4
	10.0	19.5	170	3,510	15.5	170	3,038	6,548	516	156	9.23	20.4
	15.0	19.5	170	3,510	15.5	170	3,038	6,548	516	156	9.23	20.4
	20.0	19.5	170	3,510				3,510	258	102	4.0	
	25.0	19.5	170	3,510	15.5	170	3,038	3,510	258	102	4.0	20.4
	30.0	19.5	170	3,510	15.5	170	3,038	3,510	258	102	4.0	20.4
	35.0	19.5	170	3,510	15.5	170	3,038	3,510	258	102	4.0	20.4
	40.0	19.5	170	3,510	15.5	170	3,038	3,510	258	102	4.0	20.4
	45.0	19.5	170	3,510	15.5	170	3,038	3,510	258	102	4.0	20.4
	50.0	19.5	170	3,510	15.5	170	3,038	6,548	516	156	9.23	20.4
Slope	55.0	19.5	170	3,510	15.5	170	3,038	6,548	516	156	9.23	20.4
1/4 ↑	60.0	19.5	170	3,510	15.5	170	3,038	6,548	516	156	9.23	20.4
1/3 ↓	65.0	19.5	160	3,266				3,266	226	109	3.0	20.2
	70.0	19.5	160	3,266				3,266	226	109	3.0	20.2
	75.0	19.5	190	3,851				3,851	256	139	3.0	20.2
	80.0	19.5	190	3,851				3,851	256	139	3.0	20.2
	85.0	19.5	190	3,851				3,851	256	139	3.0	20.2
	90.0	19.5	160	3,266				3,266	226	109	3.0	20.2
	95.0	19.5	160	3,266				3,266	226	109	3.0	20.2
	100.0	19.5	160	3,266				3,266	226	109	3.0	20.2
	105.0	19.5	160	3,266				3,266	226	109	3.0	20.2
	110.0	19.5	160	3,266				3,266	226	109	3.0	20.2
	115.0	19.5	160	3,266				3,266	226	109	3.0	20.2
	120.0	19.5	160	3,266				3,266	226	109	3.0	20.2
	125.0	19.5	160	3,266				3,266	226	109	3.0	20.2
	130.0	19.5	160	3,266				3,266	226	109	3.0	20.2
	135.0	19.5	160	3,266				3,266	226	109	3.0	20.4
	140.0	19.5	160	3,266				3,266	226	109	3.0	20.6
	145.0	19.5	160	3,266				3,266	226	109	3.0	20.8
	150.0	19.5	160	3,266				3,266	226	109	3.0	21.0
	155.0	19.5	190	3,851				3,851	256	139	3.0	21.1
	160.0	19.5	190	3,851				3,851	256	139	3.0	21.1

Table 8-3-3 (b) Suez Canal Dimension (Width at −11 m) (after Second Stage)

Point	km	East Channel			West Channel			Total Area (m^2)	Simplified Canal Section			
		Depth (m)	Width (m)	Area (m^2)	Depth (m)	Width (m)	Area (m^2)		Surface Width (m)	Bed Width (m)	Band Slope	Depth (m) (below M.S.L.)
	0.0	19.5	170	3,510	15.5	170	3,038	6,548	516	156	9.23	20.4
	5.0	19.5	170	3,510	15.5	170	3,038	6,548	516	156	9.23	20.4
	10.0	19.5	170	3,510	15.5	170	3,038	6,548	516	156	9.23	20.4
	15.0	19.5	170	3,510	15.5	170	3,038	6,548	516	156	9.23	20.4
	20.0	19.5	170	3,510	19.5	170	3,510	7,020	516	156	8.00	20.4
	25.0	19.5	170	3,510	19.5	170	3,510	7,020	516	204	8.00	20.4
	30.0	19.5	170	3,510	19.5	170	3,510	7,020	516	204	8.00	20.4
	35.0	19.5	170	3,510	19.5	170	3,510	7,020	516	204	8.00	20.4
	40.0	19.5	170	3,510	19.5	170	3,510	7,020	516	204	8.00	20.4
	45.0	19.5	170	3,510	19.5	170	3,510	7,020	516	204	8.00	20.4
	50.0	19.5	170	3,510	19.5	170	3,510	7,020	516	204	8.00	20.4
Slope ↑	55.0	19.5	170	3,510	15.5	200	3,503	7,013	546	173	9.56	20.4
1/4	60.0	19.5	170	3,510	15.5	200	3,503	7,013	546	173	9.56	20.4
1/3 ↓	65.0	19.5	160	3,266	15.0	200	3,315	6,581	492	183	7.92	20.2
	70.0	19.5	160	3,266	15.0	200	3,315	6,581	492	183	7.92	20.2
	75.0	19.5	160	3,266	15.0	200	3,315	6,581	492	183	7.92	20.2
	80.0	19.5	170	3,461	19.5	190	3,851	7,312	492	258	6.00	20.2
	85.0	19.5	170	3,461	19.5	190	3,851	7,312	492	258	6.00	20.2
	90.0	19.5	170	3,461	19.5	160	3,266	6,727	462	228	6.00	20.2
	95.0	19.5	170	3,461	19.5	160	3,266	6,727	462	228	6.00	20.2
	100.0	19.5	160	3,266	19.5	160	3,266	6,532	452	218	6.00	20.2
	105.0	19.5	160	3,266	19.5	160	3,266	6,532	452	218	6.00	20.2
	110.0	19.5	160	3,266	19.5	160	3,266	6,532	452	218	6.00	20.2
	115.0	19.5	160	3,266	19.5	160	3,266	6,532	452	218	6.00	20.2
	120.0	19.5	160	3,266	19.5	160	3,266	6,532	452	218	6.00	20.2
	125.0	19.5	160	3,266	19.5	160	3,266	6,532	452	218	6.00	20.2
	130.0	19.5	160	3,266	19.5	160	3,266	6,532	452	218	6.00	20.2
	135.0	19.5	160	3,266	15.0	200	3,315	6,581	492	183	7.92	20.4
	140.0	19.5	160	3,266	15.0	200	3,315	6,581	492	183	7.92	20.6
	145.0	19.5	160	3,266	15.0	200	3,315	6,581	492	183	7.92	20.6
	150.0	19.5	170	3,461	19.5	160	3,266	6,727	452	238	5.49	21.0
	155.0	19.5	190	3,851	19.5	190	3,851	7,702	512	278	6.00	21.1
	160.0	19.5	190	3,851	19.5	190	3,851	7,702	512	278	6.00	21.1

Table 8-3-3 (c) Suez Canal Dimension (Width at −11 m) (Master Plan)

Point	km	East Channel			West Channel			Total Area (m^2)	Simplified Canal Section			
		Depth (m)	Width (m)	Area (m^2)	Depth (m)	Width (m)	Area (m^2)		Surface Width (m)	Bed Width (m)	Band Slope	Depth (m) (below M.S.L.)
	0.0	24.0	240	5,568	16.0	200	3,584	12,190	874	142	15.25	24.9
	5.0	24.0	240	5,568	16.0	200	3,584	12,190	874	142	15.25	24.9
	10.0	24.0	240	5,568	16.0	200	3,584	12,190	874	142	15.25	24.9
	15.0	24.0	240	5,568	16.0	200	3,584	12,190	874	142	15.25	24.9
Slope ↑	20.0	24.0	240	5,568	16.0	200	3,584	9,152	616	147	9.77	24.9
1/4	60.0	24.0	240	5,568	16.0	200	3,584	9,152	616	147	9.77	24.9
1/3 ↓	65.0	24.0	240	5,568	16.0	200	3,488	9,104	572	187	8.02	24.7
	135.0	24.0	240	5,568	16.0	200	3,488	9,104	572	187	8.02	24.9
	140.0	24.0	240	5,568	16.0	200	3,488	9,104	572	187	8.02	25.1
	145.0	24.0	240	5,568	16.0	200	3,488	9,104	572	187	8.02	25.3
	150.0	24.0	240	5,568	16.0	200	3,488	9,104	572	187	8.02	25.5
	155.0	24.0	240	5,568	16.0	200	3,488	9,104	572	187	8.02	25.6
	160.0	24.0	240	5,568	16.0	200	3,488	9,104	572	187	8.02	25.6

(2) Result of Analysis

A harmonic analysis was not made at this time, and therefore only one cycle, beginning at 13:00h, 19th day, September 1976, has been examined. The results of the analysis are illustrated in Fig. 8-3-2 to Fig. 8-3-6.

1) Tidal level

Fig. 8-3-2 represents the lowest tidal levels at the respective points. Changing linearly between Suez and the Bitter Lake at all the stages, the water level within the Bitter Lake is almost flat at any time of the cycle. When the lowest water level below M.T.L. after the First Stage is taken as a scale, those in the Second Stage and the Master Plan increase by 40% and 70% respectively. This lowering of the water level tends to diminish gradually toward the north of Lake Timsah to 0 at Port Said. The low water level in the Bitter Lake shows a slight negative gradient toward Port Said, and this is considered to be due to difference in setting the cross-sectional area between the water level point and the flow point, and the difference of salinity and wind stress. However further examinations with field observations are needed to clarify the reason.

Fig. 8-3-3 (a) through (c) show the profile of the water surface at the respective stages of development. Between the Bitter Lake and the Lake Timsah, the water surface shows a positive gradient toward Port Said at all times, clearly denoting the storing effect of the Bitter Lake and the difference of mean tide level between both ends.

Fig. 8-3-4 shows the change with time of the tidal level at Suez (Km 160), Shallufa (Km 140) and the Bitter Lake (Km 115). At Km 140, the tidal level changes approximately with the same phase as that at Suez, but at the Bitter Lake, there is a phase delay of 3–4 hours.

2) Tidal current

In Fig. 8-3-5 is shown the change with time of the tidal current along the Canal. Between Suez and the Bitter Lake, the tidal current flows alternating southwards/northwards, but to the north of the Bitter Lake, only the southward current occurs except for the Master Plan. The extent of change due to difference of Canal sections at the respective stages of development is largest in the section to the north of the Bitter Lake.

In Fig. 8-3-6 is shown the tidal current velocity along the Canal.

(3) Evaluation of result

It might be hasty to make any quantitative decision from the result of limited analysis conducted this time on the design of the Canal section and the operation and management of the Canal in the future. But, from the result of analysis, it is possible to predict the qualitative trend of the tidal current associated with the expansion of the canal section.

1) Tidal level

A change of the tidal level resulting from the development of the Canal, or more exactly, lowering of the lowest tidal level along the Canal leads to decreasing effective water depth of the Canal.

Should the lowest tidal level at the respective points come below the datum level taken presently, it will be required to increase the dredging depth. From the result of analysis, lowering of the tidal level due to expansion of the Canal section will occur to the south of the Lake Timsah. According to the Report of Maunsell Consultants Ltd., the lowest tidal level after completion of the Second Stage Project is only about 10cm higher than the datum level in the Bitter Lake (on a typical November condition). Therefore, it will be necessary to check whether a change in the datum level is required particularly after the Second Stage (doubled channels) and the Master Plan are realized.

In the case of a doubled Canal, the difference in water level due to a phase difference between the two channels generates a transversal flow at the junction points. The analysis conducted this time was with a simplified single channel, so that it is not possible to analyze the trend of such a transversal flow. This should be examined further.

2) Tidal current

With respect to the tidal current, no appreciable change was observed south of the Bitter Lake. However, north of the Bitter Lake the current velocity increases with the increasing tidal range in the Bitter Lake. This increase is not so serious to affect ship maneuverability. But, in sections where the bank consists of silty sand, increasing siltation is possible. The mechanism of littoral drift itself has not been clarified presently, so any forecasting of siltation is difficult. But, it is important to estimate the siltation rate through observation at the site, so that a precise dredging plan may be formulated.

Further, at the junction points of the two channels, there is a possibility that the different tidal current velocities may produce a complex flow between these two channels, together with the difference of the tidal level. For example, at the stage of Master Plan, these two channels join each other at 9 points, namely i) Gulf of Suez, ii) Ahmed Hamdi Tunnel, iii) Geniefa, iv) Deversoir, v) Km 75, vi) Both ends of Ballah Bypass, and viii) Both ends of Port Said Bypass. At these junction points, the tidal currents in these two channels interact due to differences in velocity and phase to produce a complex flow. Such a phenomenon does not occur at any place in the present Canal. An analysis should, therefore, be made through numerical calculation and hydraulic experiment to examine any effect on the maneuverability of ships, and thereby formulate an adequate plan for the layout and cross-section of the Canal.

It is, of course, imperative to check the change in maneuverability due to cross-sectional change at such points, even if there is no remarkable change of the tidal level or current.

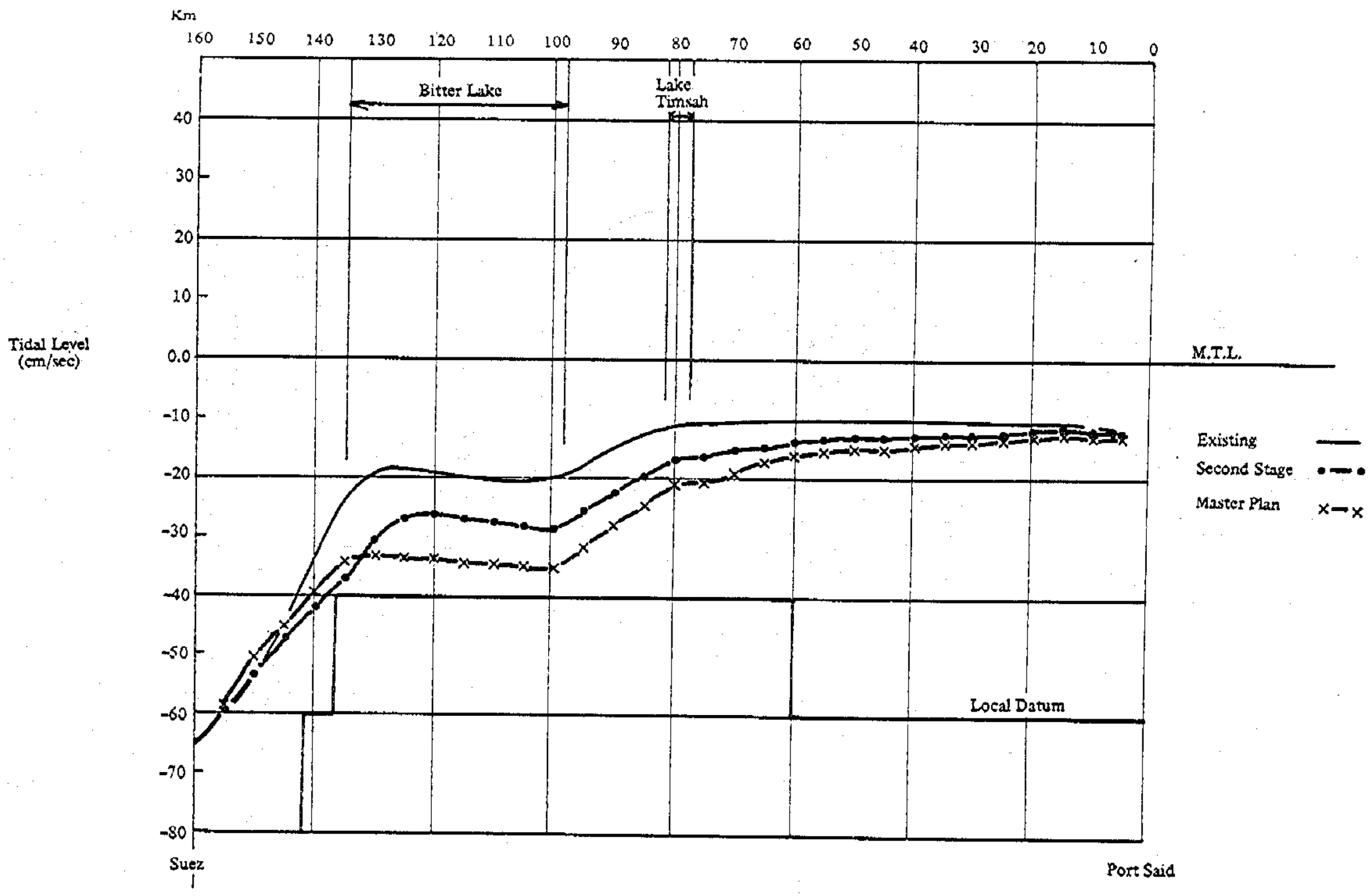


Fig. 8-3-2 Low Tidal Level along the Canal

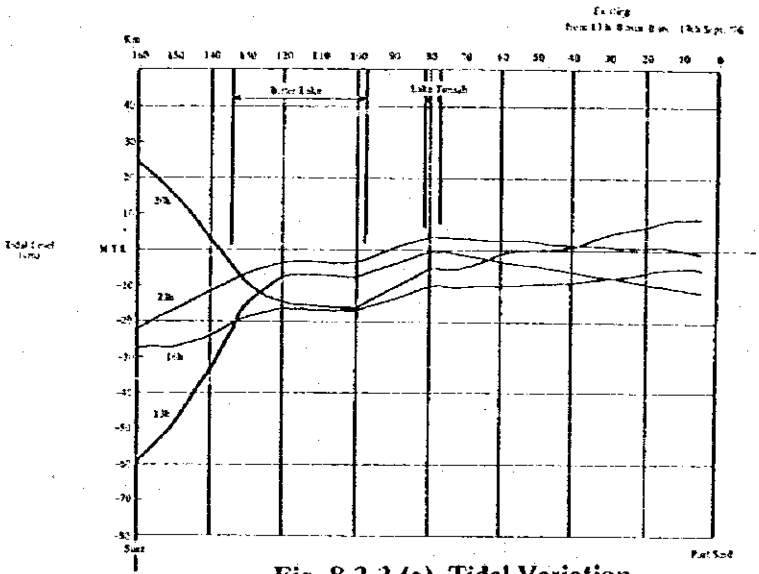


Fig. 8-3-3 (a) Tidal Variation

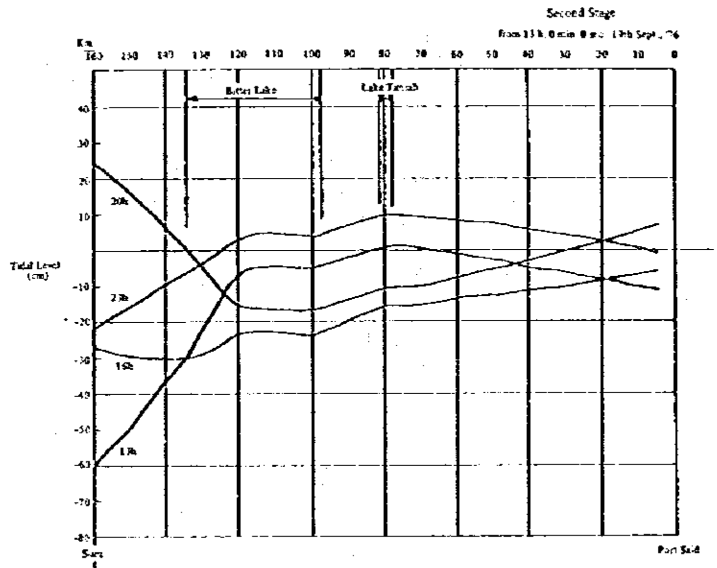


Fig. 8-3-3 (b) Tidal Variation

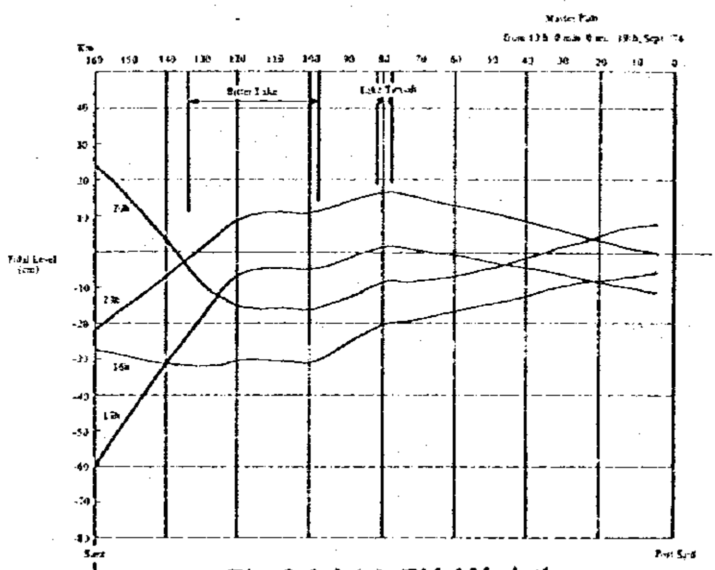


Fig. 8-3-3 (c) Tidal Variation

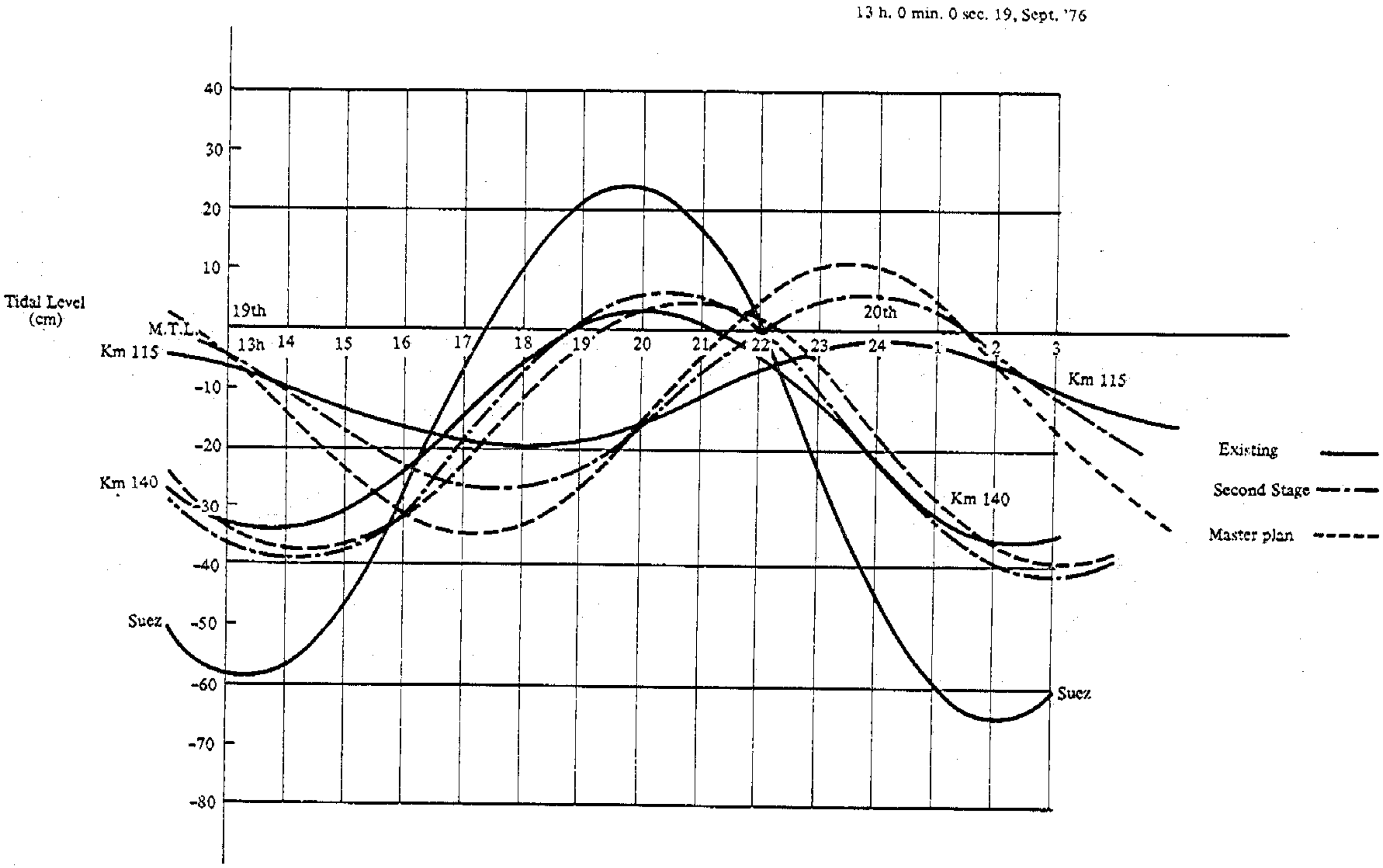


Fig. 8-3-4 Tidal Variation
(km 115, km 140, km 160)

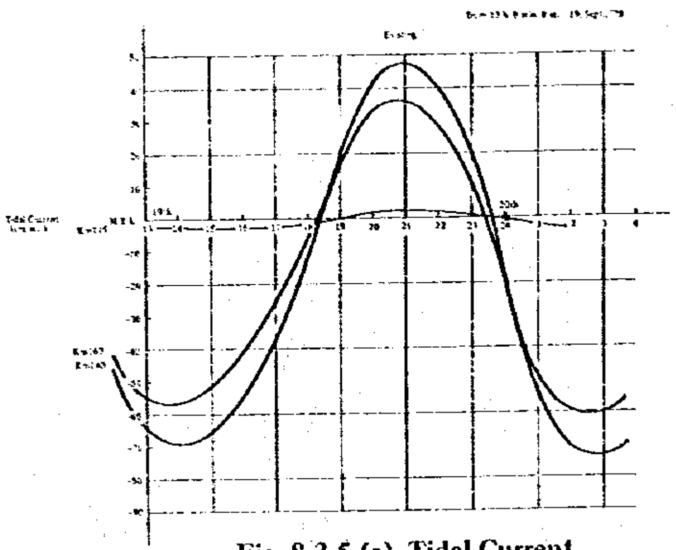


Fig. 8-3-5 (a) Tidal Current
(km 115, km 140, km 160)

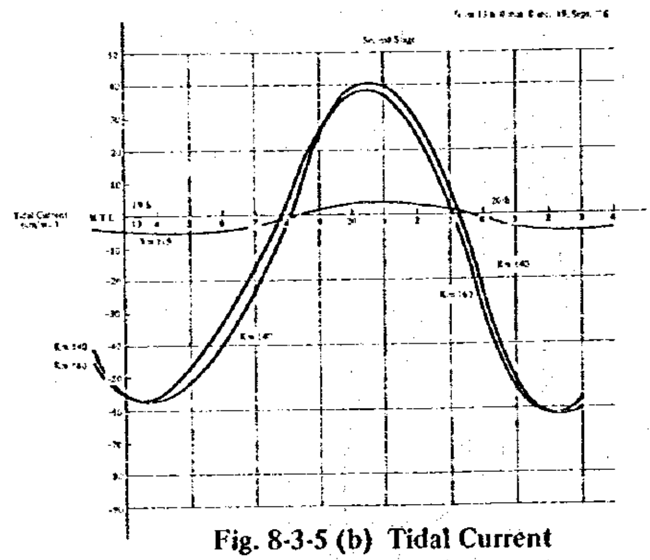


Fig. 8-3-5 (b) Tidal Current
(km 115, km 140, km 160)

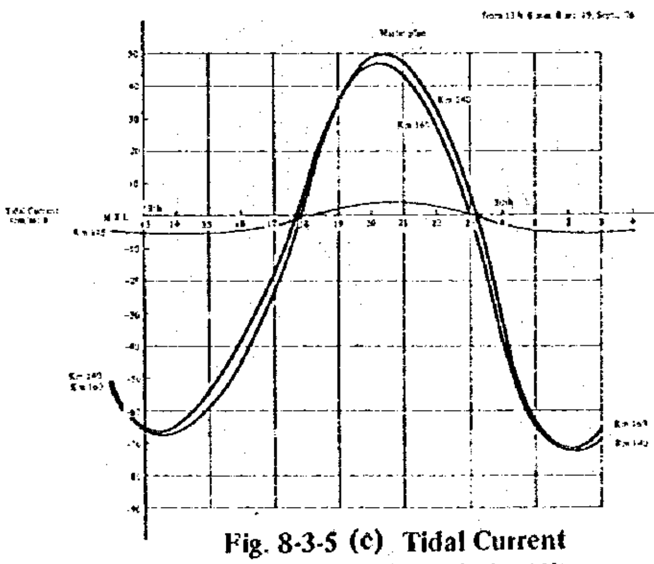


Fig. 8-3-5 (c) Tidal Current
(km 115, km 140, km 160)

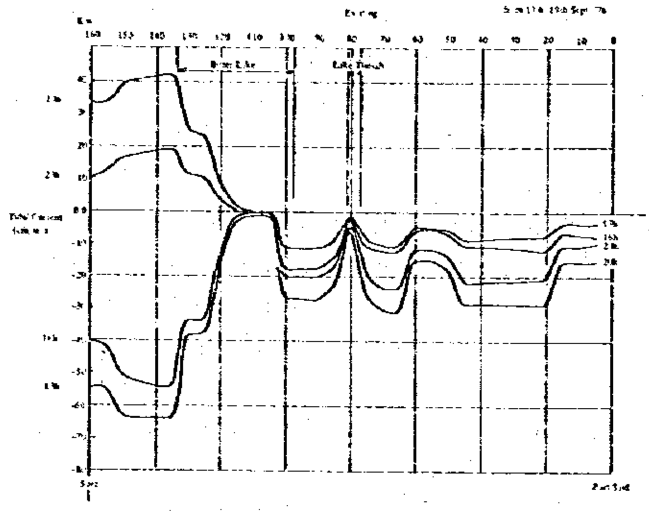


Fig. 8-3-6 (a) Tidal Current

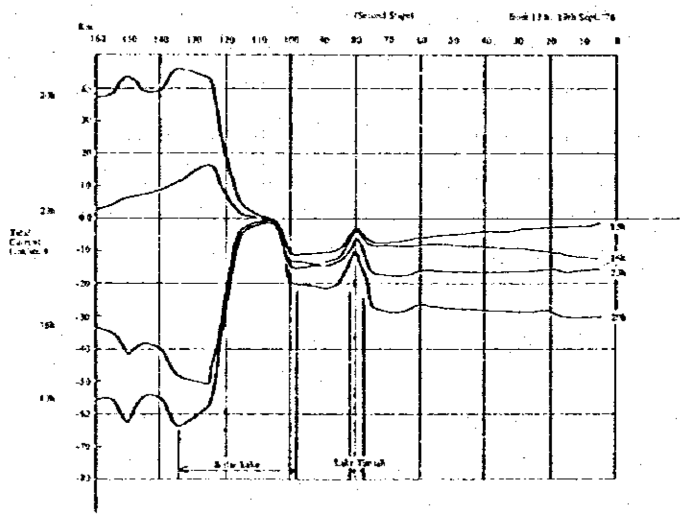


Fig. 8-3-6 (b) Tidal Current

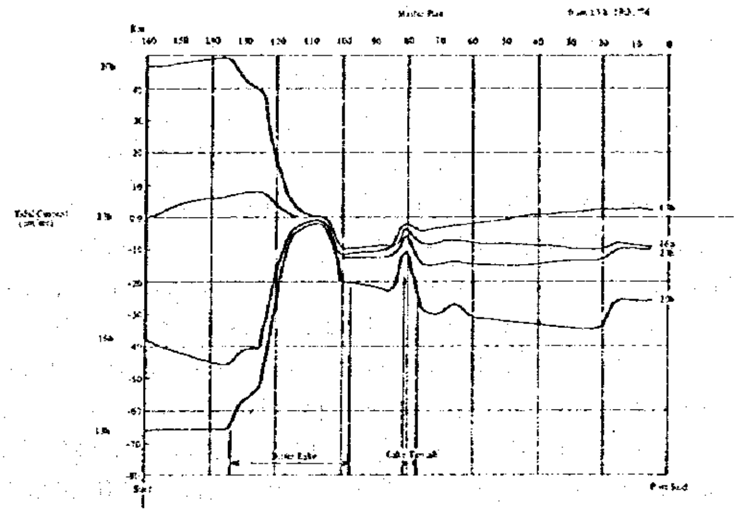


Fig. 8-3-6 (c) Tidal Current

4. Stability of Canal Bank

4-1 Soil condition along the Canal

(1) Available data

Data available for soil conditions along the Canal are comprised mainly of those concerned with dredging. As information concerning soil conditions covering the extensive area along the Canal, there are data obtained from about 200 borings conducted in 1975 by Raymond International Inc. These data include the results of standard penetration tests (N value) and the physical properties of soils at each depth. The bore hole interval in this survey is rather long (1~3 bore holes/km), but the data have been used actively as the basic data for dredging. In 1976, a seismic reflection survey of the Canal was conducted by EG & G Geophysical Ltd. of England. Based on the results of the seismic reflections along the center line of the Canal, on the east bank and in a transversal direction, a map of geological structure by computer analysis was prepared. Such data seem to be useful to obtain some rough information on geological profiles, but it is not certain whether they are reliable.

Upon comparison with the data of dredging along the region Km 97.8 to Km 122, the engineers of the Penta-Ocean Construction Co., Ltd. reported orally that they were relatively in good agreement. Based on the basic data such as those stated above, the SCA Research Center has presented several series of reports on soil conditions along the Suez Canal. Such reports include:

1) Soil Report – Lot (H) and New Port Said Bypass (Km. 1.500E – km. 16.000 E), SCA Research Center Report No. 92, March 1977.
2) Soil Investigation at The Approach Channel of The Port Said New Bypass Lot(L), SCA Research Center Technical Report No. 93, July 1977.
3) Soil Report of The Region from Km.25.000 to Km.61.000, SCA Research Center Technical Report No. 91, Nov. 1976.
4) Soil Report of Tossom Zone from Km.78.000 to Km.98.000, SCA Research Center, Dec. 1976.
5) Soil Report of the Region from Km.97.800 to Km.122.000, SCA Research Center Report No. 89, Dec. 1976.

The foregoing soil tests and investigation in the Suez Canal region were conducted mainly for obtaining information on soil for dredging and were not always satisfactory as soil information required for designing such as stability check of the canal bank and earth pressure calculation. Later, in relation to excavation of the New Port Said Bypass, soil investigation including sampling of undisturbed soils and unconfined compression test of such samples were carried out during the period from March to July 1978. These investigations were conducted at 2 bore holes along the center line of the New Port Said Bypass (land boring), 3 bore holes on the east bank of the bypass (sea boring) and 3 bore holes on the west bank of the Bypass (sea boring), and included standard penetration tests and soil profile diagrams as well as unconfined compression tests (by automatic recording type test apparatus, Seikensha). The results of these tests are summarized in the Soil Report- New Port Said Bypass (km.1.500E – Km. 16.000E). However, the data on unconfined compressive strengths seem to be influenced by sample disturbance to an appreciable extent, hence it is doubtful if they can be used for data on slope stability, earth pressure and other design calculations. In this survey, percussion boring was employed to drill test holes, from which soil samples were taken by an open drive sampler. While there was a problem in the method of cleaning the bored bottom on one hand, the method used for boring and sampling seemed to have induced disturbance of the samples on the other.

With respect to the soil in the vicinity of the Port Said Port, the reports by the Golder Associates "Port Said Urban Land Reclamation Design Study, Vols. 1, 2 & 3, Jan., 1979" include valuable information. These reports represent the results of the survey concerning the reclamation of the Port-Said area and provide data on the locations close to the Suez Canal. In these surveys, results of the standard penetration tests, soil profile diagrams, laboratory vane tests, triaxial UU (unconsolidated-undrained) tests, consolidation tests and field vane tests were reported.

(2) Soil property along the Canal by the available data

General information on the soil along the extension of the Canal is obtainable from the data of about 200 borings by Raymond International Delaware Inc. and the results of the seismic reflection survey by EG & G Geophysical Ltd. and also the SCA Research Center Technical Reports which sum up the foregoing two for each work lot of the Suez Canal. From such information, features of the respective sections along the extension of the Canal are described below:

1) Km 0~13 section

To a depth of 10m below the datum level, loosely packed sand with the N value of about 10 prevails, and a stratum of shell of 20~30 of the N value exists from place to place. Relatively soft clayey soil exists at a depth of 10~15m, and beneath it, almost uniform silty clay or clay is found (N value of 2~6).

2) Km 13~38 section

To about 25m below the datum level, silty clay prevails. It is relatively soft from Km 13 to Km 25 and is relatively hard from Km 25 to Km 38. Between Km 33 and Km 38, compacted sand appears beneath the depth of about 20m.

3) Km 38~61 section

In the section including the Ballah Bypass from Km 38, relatively soft silt is included in the surface layer, but a very hard sand layer generally prevails. With respect to the stability of the slope, it should be noted that at Km 52 a silty clay layer with the N value of 4 to 5 is present to a depth of about 25m.

4) Km 61~78 section

In the section from the Ballah Bypass to the Lake Timsah, a very hard gravel layer generally prevails.

5) Km 78~86 section

In this section from the Lake Timsah to Toussoum, the soil condition is variable, but sandy soil generally prevails. The surface layer has a deposit of relatively loose sand below which a gravel layer is found. Limestone layers are also seen here and there.

6) Km 86~97 section

To about 10m below the datum level is seen a slightly compacted sand layer or cemented clayey soil. Thereunder, a hard gravel layer is present.

7) Km 97~120 section

The greater part of the Great Bitter Lake is comprised of halite, and at about 20m below the datum level appeares a slightly compacted sand layer.

8) Km 130~135 section

In this section the Little Bitter Lake is located, and the soil is composed of hard clay, medium to very hard gravel, and limestone or sand stone appeares from place to place.

9) Km 135~160 section

From Km 135 to Km 144, the surface layer is composed of medium to very hard clay, and at 10~12m below the datum level appeares vey hard cemented clay. From Km 144, a very dense cemented sand layer is present under the hard clay layer. Further, from Km 157, gravel and pebbles exists in the hard sand layer, and layers of limestone and sand stone are also found.

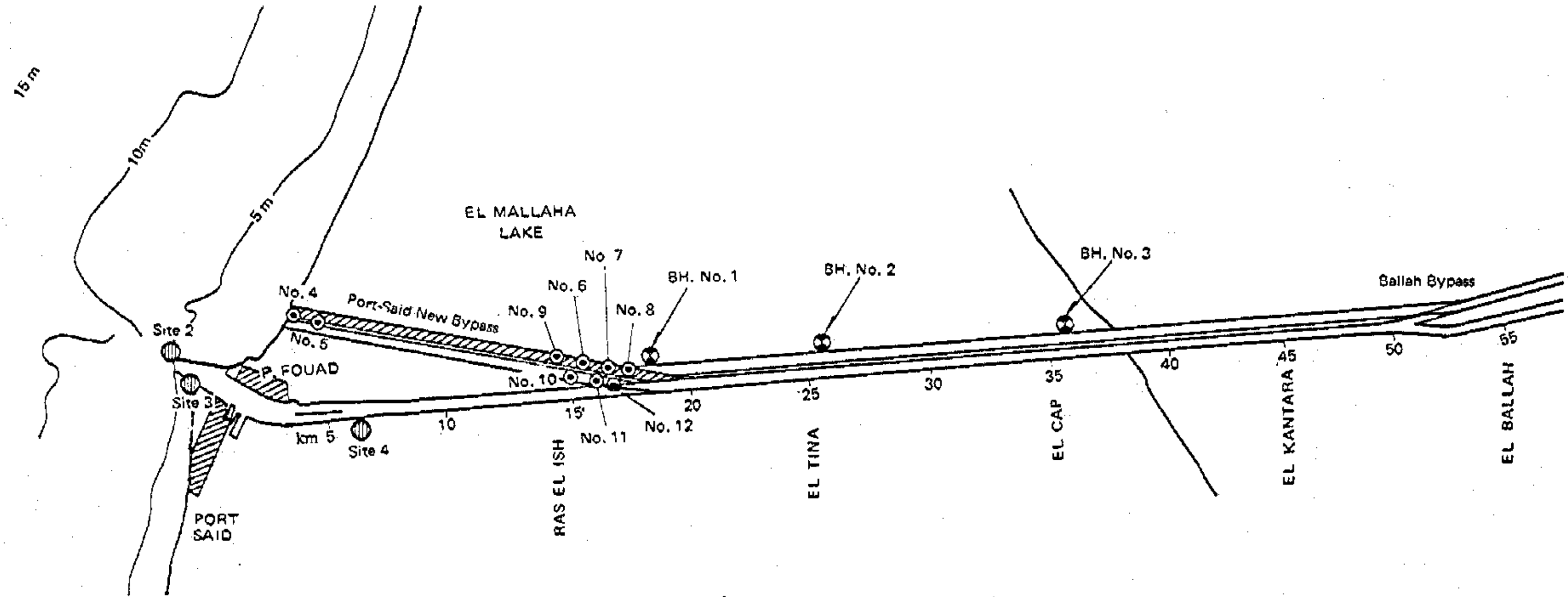
(3) Soil data for geotechnical examination

From the soil survey of the Canal region conducted by the Raymond International Delaware, Ltd. and the several volumes of Soil Reports of the SCA Research Center, a general survey of the soil conditions of the Canal is available, which may give useful information on soils for the dredging. However, for geotechnical examination including slope stability and earth pressure calculations, the information is hardly said to be satisfactory. The standard penetration test so far employed in the soil survey of the Suez Canal is an adequate method for evaluation of the sandy subsoil, but is not adequate for the clayey subsoil or, more particularly, soft subsoil with the N value less than 4. Examination of the stability for the clayey subsoil is made usually from the information of the unconfined compressive strength qu. Thus, the value of qu is sometimes estimated from N value of the standard penetration test using an empirical correlation. But, the correlation between the penetration number and the shear strength of cohesive soils scatters to a considerable extent, and thus the validity may be suspect. For the clayey subsoil, it is considered to be the most appropriate method to conduct an unconfined compression test on undisturbed samples.

The examination of the stability of the canal slope is one of the most important problems for design and executing and from such a point of view, field experiments on slope stability and soil surveys were started by the SCA Research Center. For the purpose of constructing the New Port Said Bypass, a soil survey including collection of undisturbed samples was conducted at locations shown in Fig. 8-4-1.

The results of soil test and investigation at the location along the New Port Said Bypass shown in Fig. 8-4-1 are described in the Soil Report – New Port Said By-pass (Km.1.500E – Km.16.000E).

The logs at these bore holes are shown in Fig. 8-4-2. Unconfined compression tests were carried out on samples taken at the site. But, the test results show a considerable effect of sample disturbance followed by underestimation of the value of qu because of the unsuitable methods of boring and sampling, as stated above. For the purpose of excluding data under great influence of the disturbance, only data with the failure strain less than 6.0% in the unconfined compression test were employed and plotted against the depth, as shown in Fig. 8-4-3. The value of R in Fig. 8-4-3 represents the ratio of the number of the data adopted to the total number of unconfined compression tests conducted on samples taken in the respective boring holes. A solid straight line in Fig. 8-4-3 shows the representative curve for the variation of the unconfined compressive strength with depth at the excavation site of the New Port Said Bypass. With respect to these results, it should be noted that the unconfined compressive strength is considerably underestimated because of sample disturbance in sampling.



Sampling data available to unconfined compression tests

Site 1: New Port Said Bypass project by S.C. Research Center, 1978

Site 2: Mechanical Ship Lift 750T at Port Foud by S.C.R.C. 1978/8

Site 3: Floating Dry Dock 10,000T at Port Foud by S.C.R.C, 1978/

Site 4: Port Said Urban Area Reclamation Project by Golder Associates 1979/1

Fig. 8-4-1 Sites for Soil Investigation

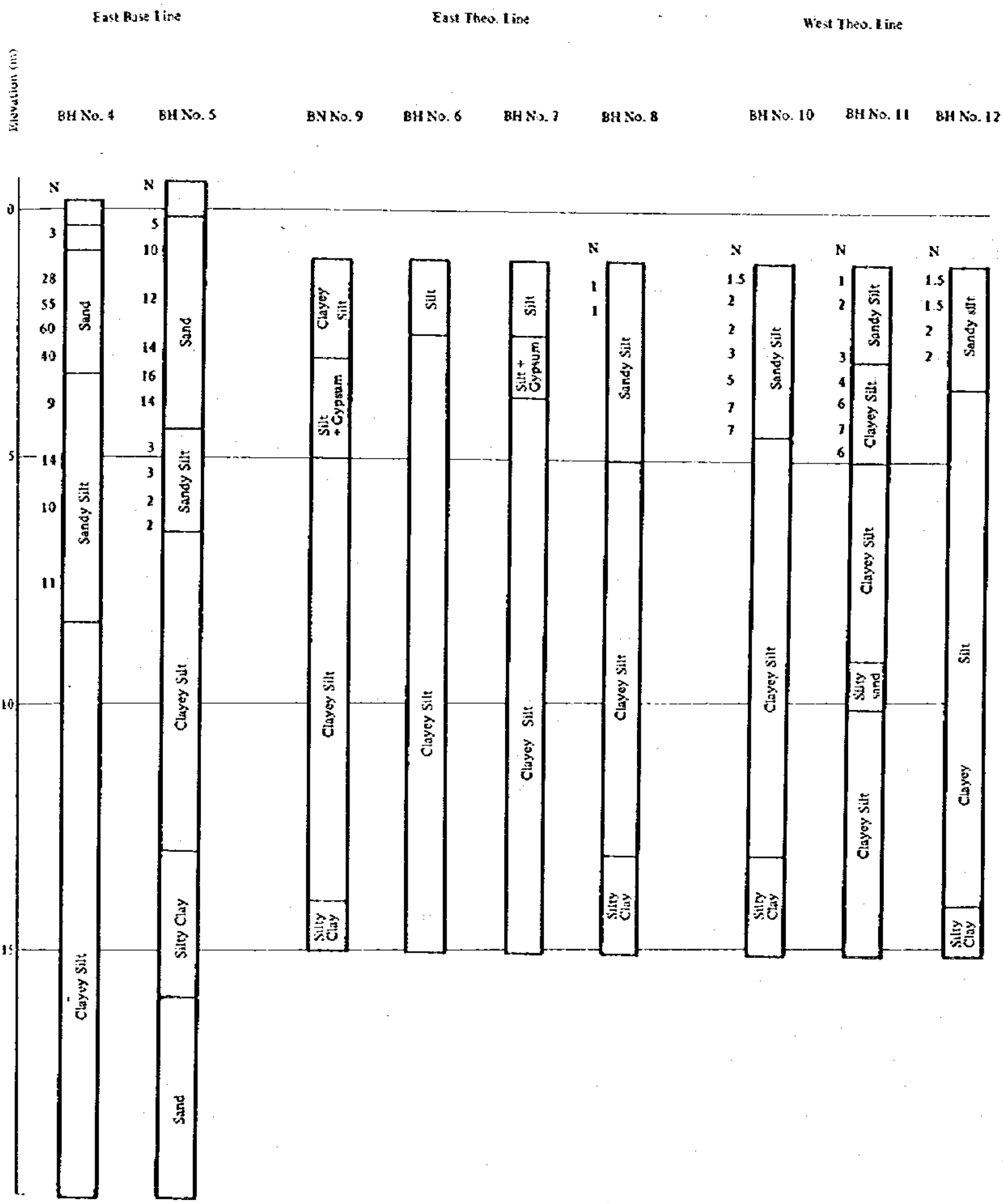


Fig. 8-4-2 Soil Profile (Port Said New Bypass)

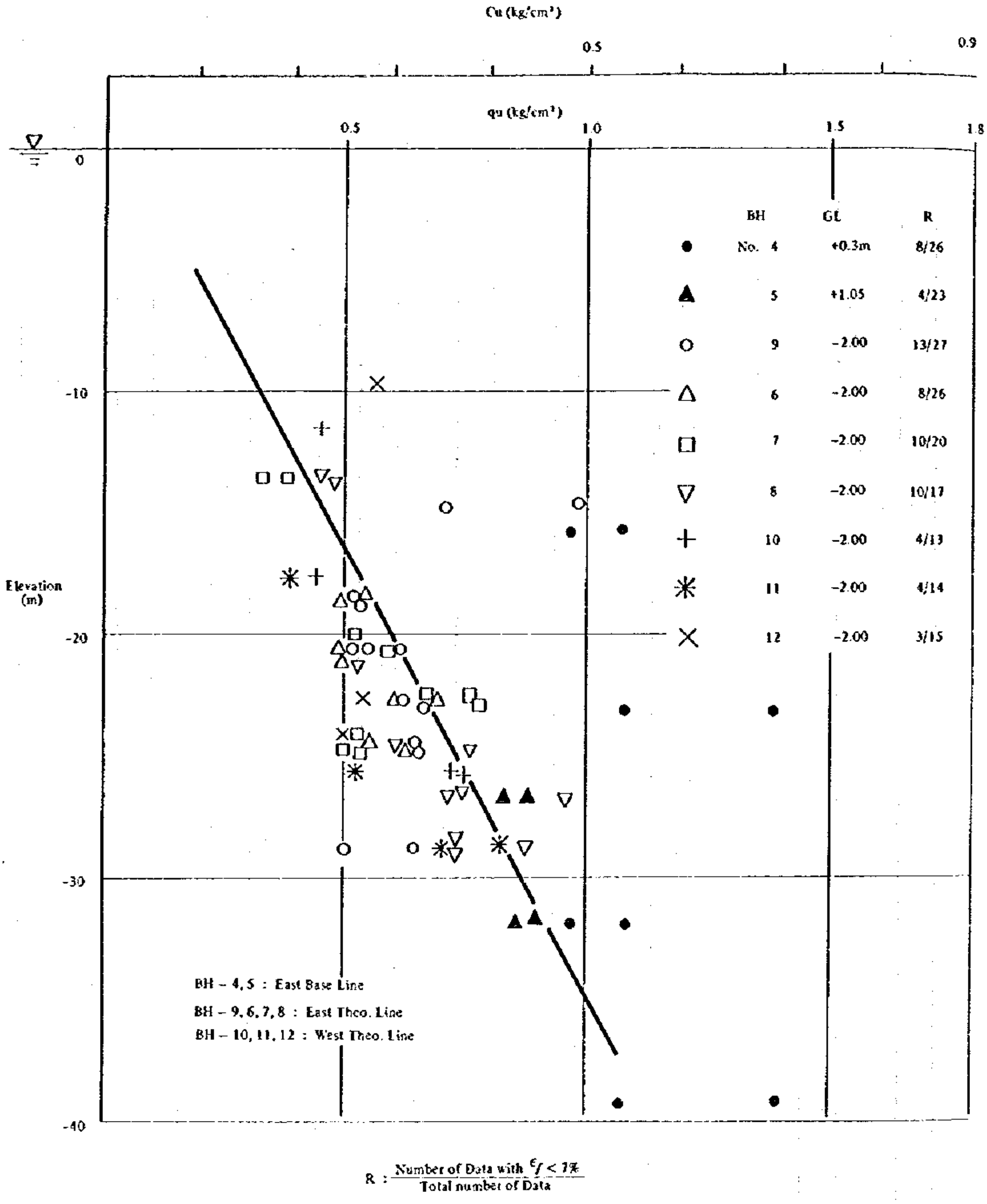


Fig. 8-4-3 Variation of qu with depth (km 5, Port Said New Bypass)

(4) New Soil survey in the Canal

For the geotechnical examination such as slope stability calculation, reliable data of soil condition are required. For the purposes of both satisfying such requirement and verifying the usefulness of the stationary piston thin wall sampler, a new soil survey was planned and carried out by the soil mechanics group of the SCA Research Center under the cooperation of Civil Engineers of the Port and Harbour Research Institute of the Ministry of Transport, Japan, Mr. Umehara and Mr. Horie late 1979. Along the Canal, soft clayey soil prevails from Port-Said to Km 61, and the inclination of the side slope is 1 in 4 along the northern 61 km, and 1 in 3 along the remaining length. In view of such situation, three survey sites were chosen as shown in Fig. 8-4-1. They are Km 16.2, Km 25 and Km 35.2 which may represent three types of locations consisting of very soft clayey soil, somewhat hard clayey soil and hard clayey soil respectively. In Fig. 8-4-4 are shown the sampling positions and sampling methods at these 3 bore holes. Samples collected were subjected to unconfined compression tests and physical tests at the soil laboratory of the SCA Research Center in Ismailia.

In Figs. 8-4-5, 8-4-6 and 8-4-7 are shown the variation of the unconfined compression strength qu and failure strain, Ef with depth at Km 35.2, Km 25.0 and Km 17.6 respectively. The test results on samples taken by both stationary piston thin wall samplers and open drive thin wall samplers are shown separately. While the detailed examination of the test results will be given in the report of the SCA Research Center, the values of unconfined compressive strength thus obtained seem to be reasonable judging from the trend of failure strain. In each of Figs. 8-4-5 to 8-4-7, the variation of qu with depth is shown by a solid line. A dashed line in Fig. 847 represents the variation of average values of qu with depth, which was obtained from the soil investigations for the excavation of the New Port Said Bypass stated above. The results are considered to include underestimations of qu due to disturbance of the samples, but the result of survey at Km 17.6 seems to indicate that the influence of sample disturbance has been removed considerably.

In geotechnical examination such as slope stability calculation of the clayey subsoil, information on the unconfined compressive strength qu is fundamentally important. But, in some cases, the unconfined compressive strength must be estimated indirectly, for example, by the use of the N value. However, any correlation between the N value and the qu value for cohesive soils is of considerable variation over a wide range, as shown in Fig. 8-4-8, so that selection of an adequate empirical formula applicable to any place seems to be generally difficult. When a correlation is established for a certain location, it will be of significant reference for estimating the characteristics of soil at least in the vicinity. Fig. 8-4-9 shows the variation of the N value with depth and that of qu with depth for Km 35.2. From both data, a general correlation between the N and qu is shown in Fig. 8-4-10. In this figure is also shown the correlation proposed by Terzaghi et al. The N-qu correlation for Km 35.2 can be seen to give considerably greater qu than the value proposed by Terzaghi et al.

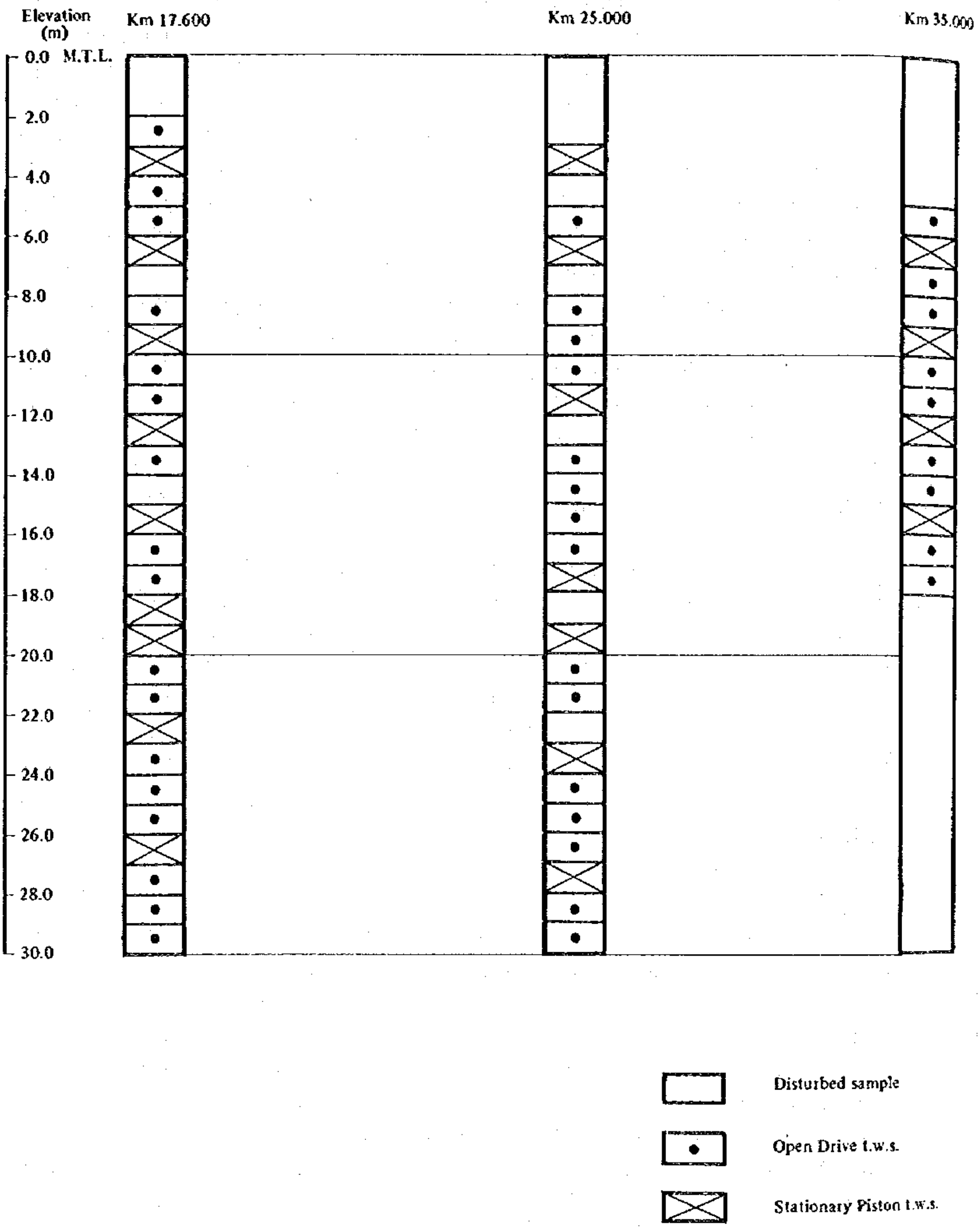


Fig. 8-4-4 Schematic Profiles showing the Sequence of Sampling Locations

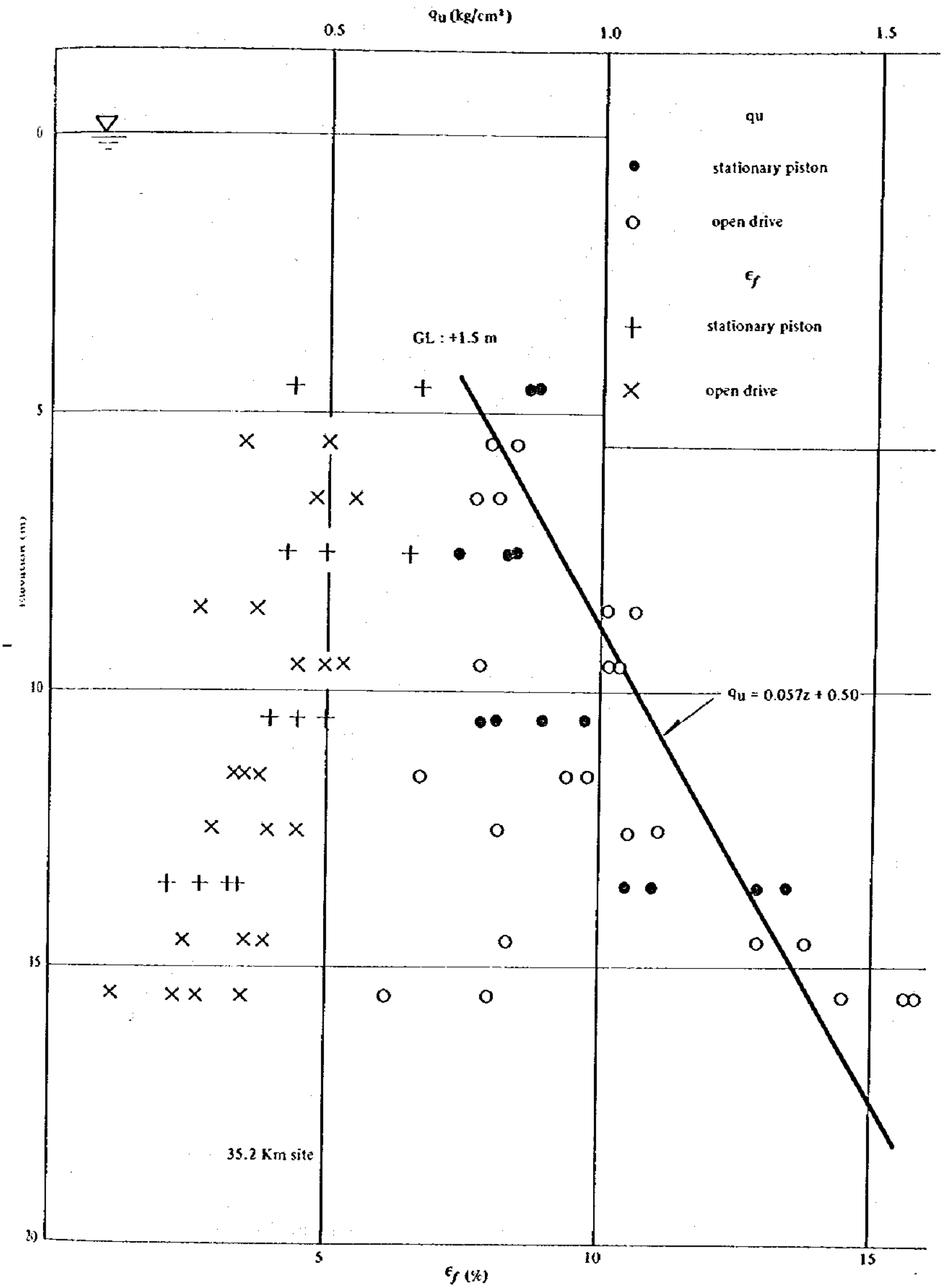


Fig. 8-4-5 Variation of qu with depth (Km 35.2)

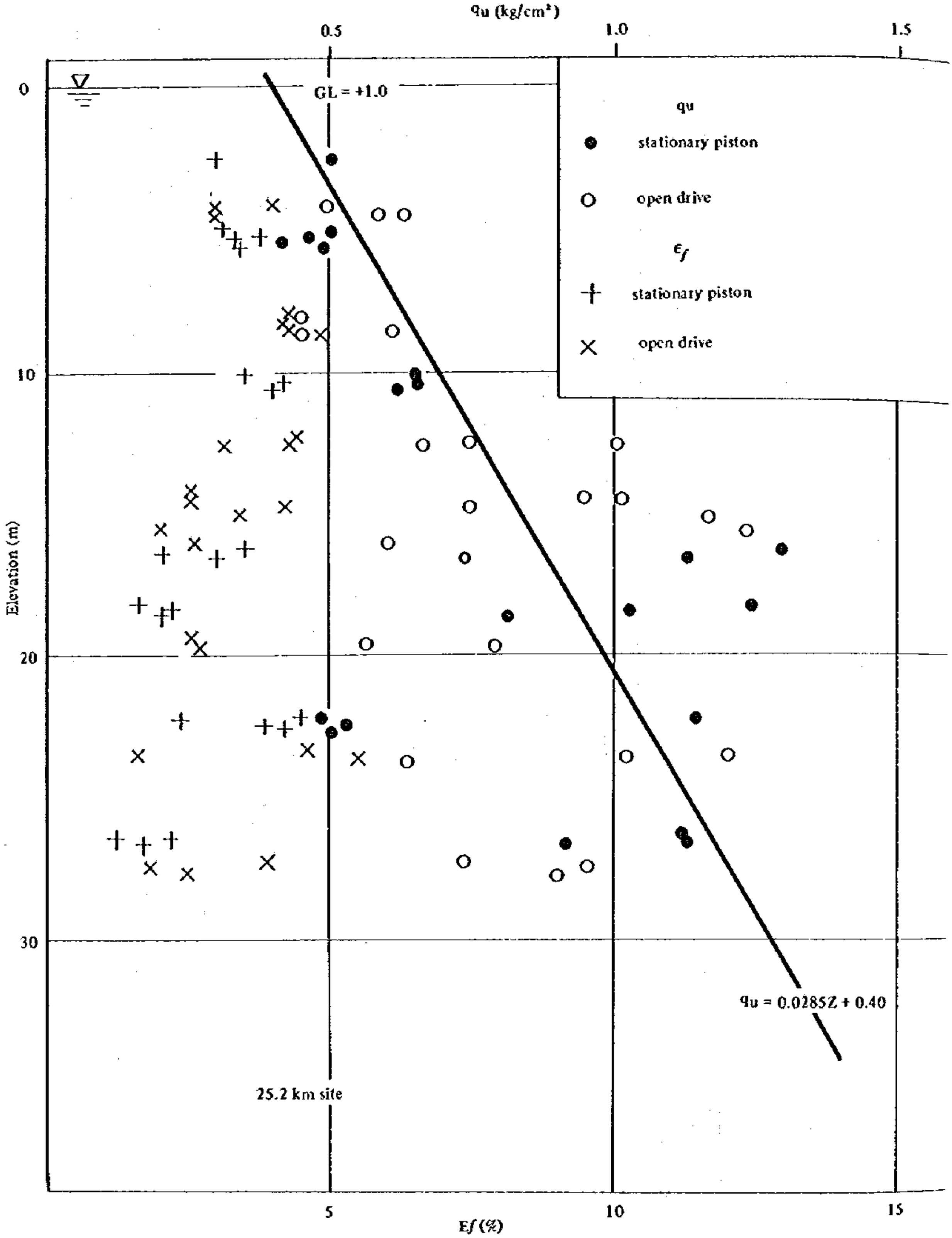


Fig. 8-4-6 Variations of qu and ϵ_f with depth (Km 25.2)

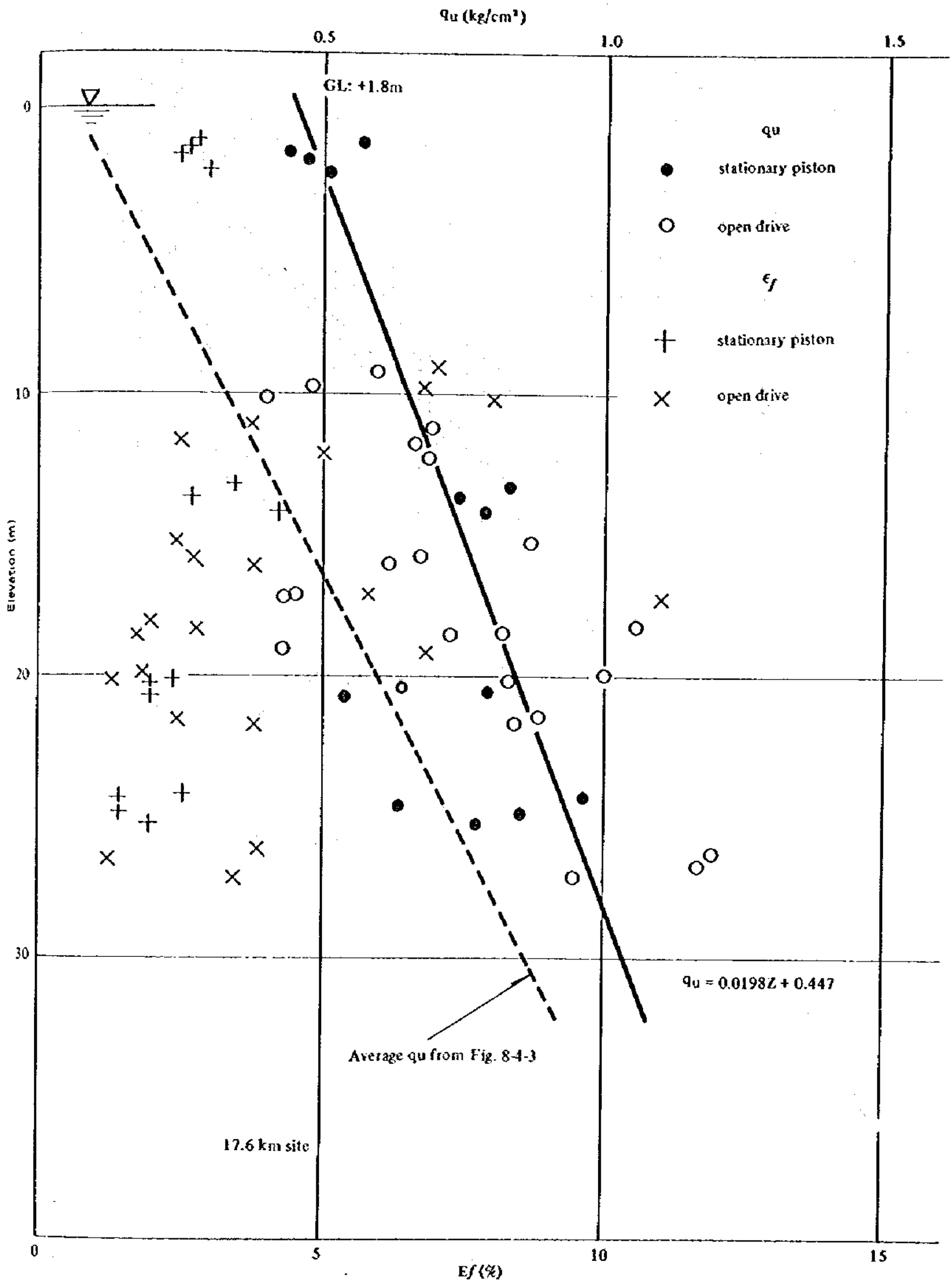


Fig. 8-4-7 Variations of q_u and ϵ_f with depth (Km 17.6)

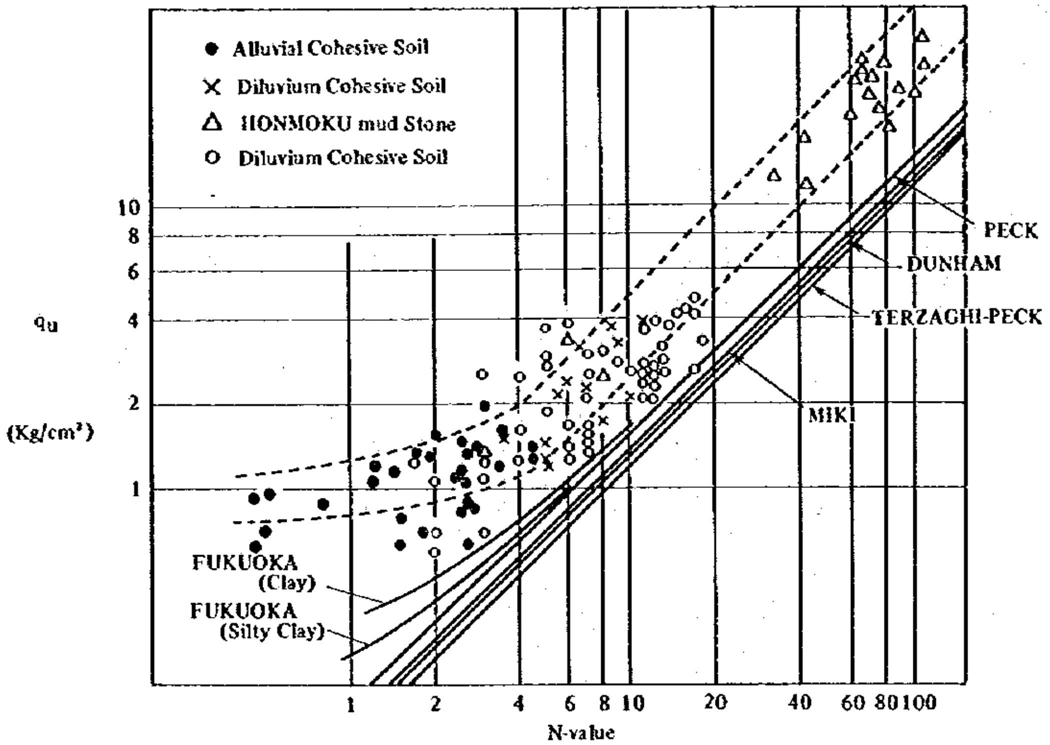


Fig. 8-4-8 Relation between q_u and N value

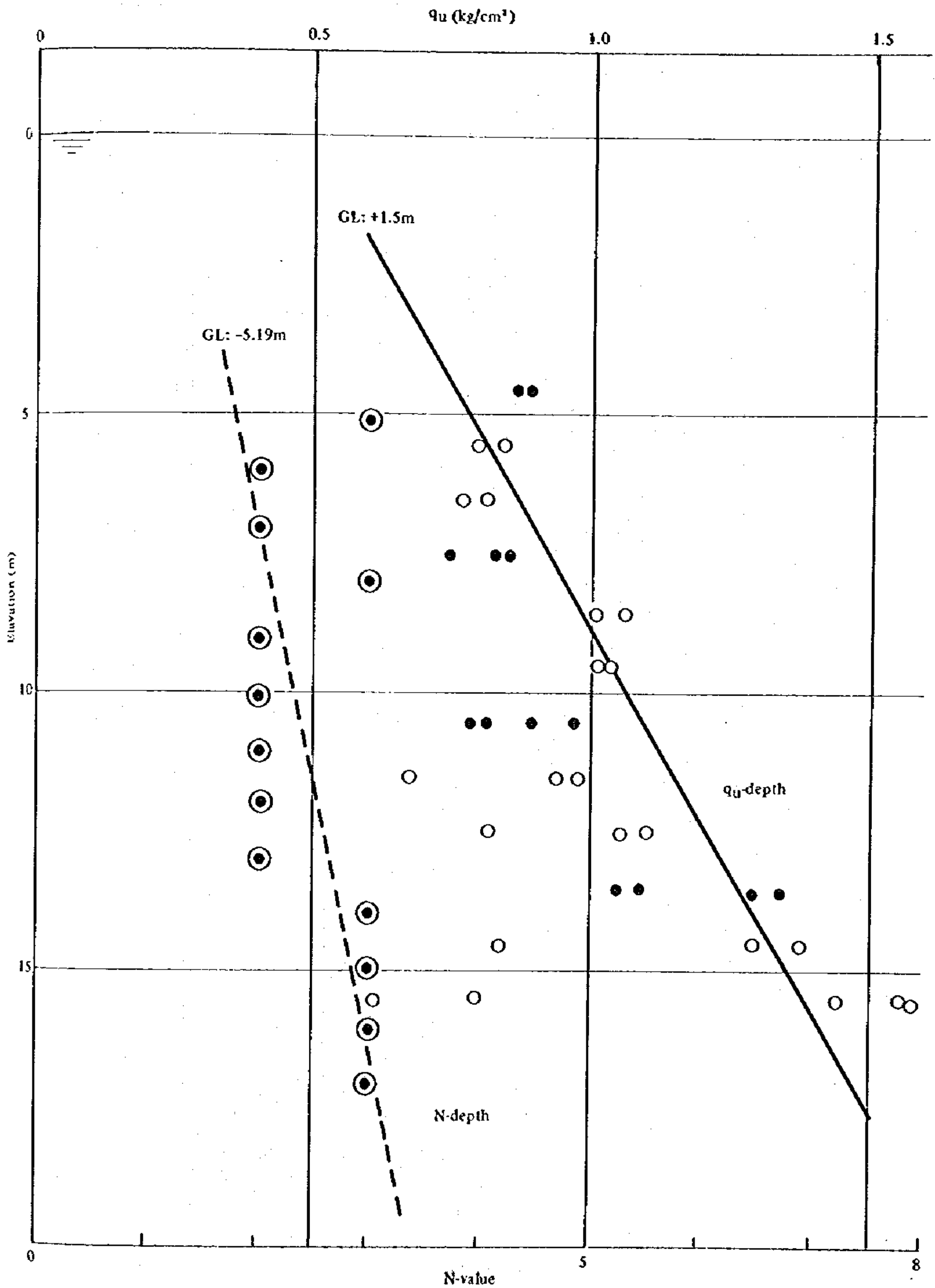


Fig. 8-4-9 Variations of qu and N with depth

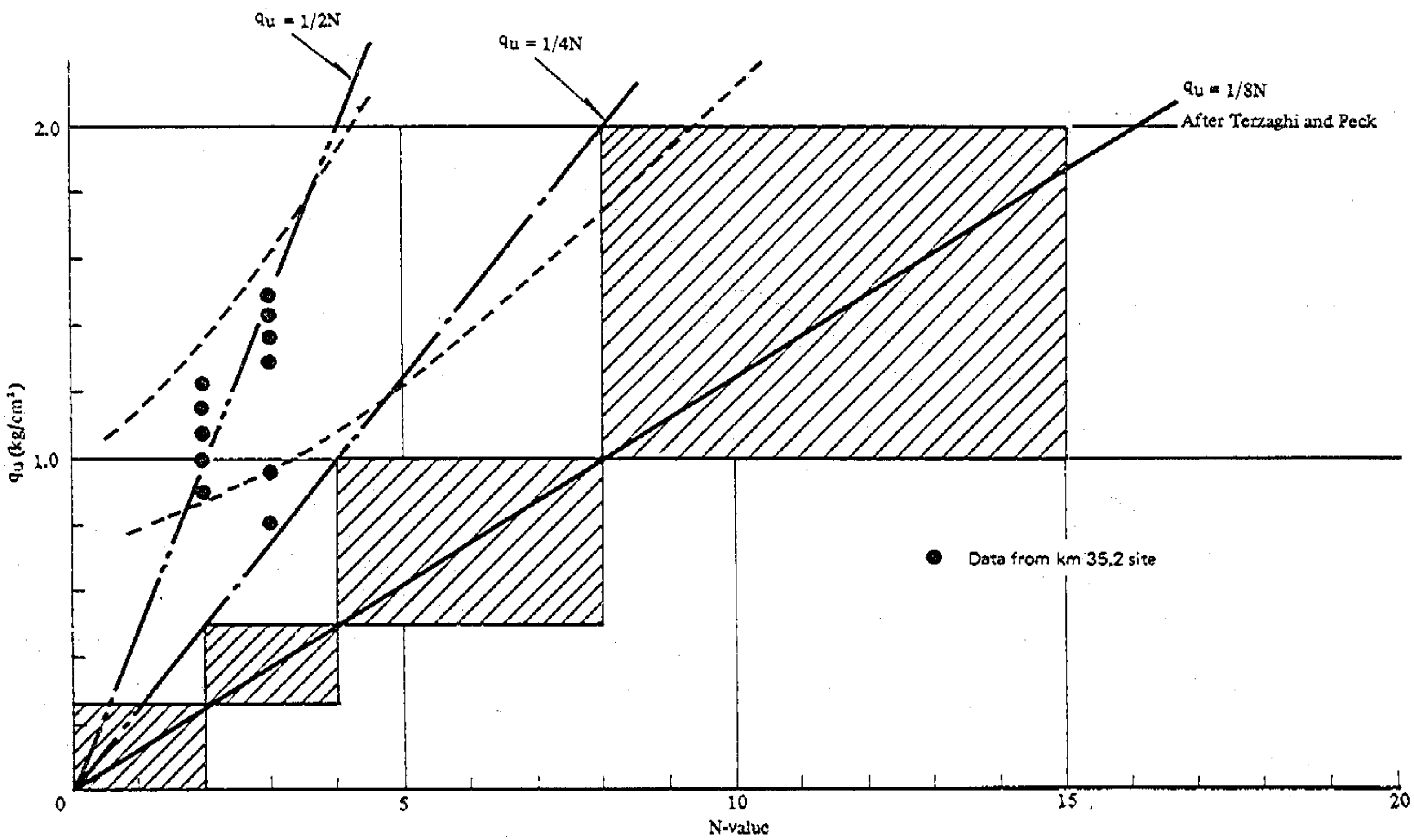


Fig. 8-4-10 q_u versus N value

4-2 Stability of Canal Bank against Circular Slip

The examination of the stability of canal banks may be categorized into two major parts, namely, that for a long period such as scouring, etc. and that for a very short time such as circular slip. A circular slip is much more dangerous than the former, because it may cause rapid movements of a large amount of soil mass in a very short period. With respect to the stability of the canal bank against the circular slip, Sogreah conducted several series of computor analysis for various cross-sectional profiles under different soil conditions predicted from a limited number of soil data and pointed out that some banks consisting of clayey soils with low cohesion might be unstable. Therefore, the stability of the section banks has been rechecked here using the data described in the previous section.

(1) Canal profile and soil condition

The cross sections checked in the present analysis are those for the following four locations whose soil conditions are determined by the recent soil investigations.

(a) Km 5 (Port Said Bypass).
(b) Km 17.6.
(c) Km 25.2.
(d) Km 35.2.

The Canal profiles and soil conditions are shown in Fig. 8-4-11 and Table 8-4-1. The slope gradient is 1/4, and the ground height is +2.0m, with the canal water depth at 19.5m and 24m as corresponding to the First and Second Stages and Master Plan. For the soil condition, the variation of cohesion with depth was given linearly according to the test results stated above (Fig. 8-4-12). The water level was assumed as −1.20m in consideration of the temporary lowering of water level due to the navigation of ships. For Km 5, an intra-slope failure near the slope shoulder became the most critical (retest of the soil would be required), hence the stability of the whole slope was examined of a cross-section with a berm. For Km 35.2, a slightly sloped sand layer exists under the clay layer at an elevation of about −20m, but in computation it was simplified as lying horizontally.

Unit weight of soil in water

The test results on the unit weight of soil were not available at the time of computation. Thus, the test results conducted by Kotzias-Stamatopoules at the locations very close to the sites considered were used as shown in Table 8-4-2. By averaging the data from Km 7.7 to Km 23 in Table 8-4-2, the wet unit weight is determined as $1.7 t/m^3$ and the submerged unit weight is determine as $0.7 t/m^3$.

Table 8-4-1 Soil Characteristics

Location	Cohesion (t/m^2)	Angle of Repose (°)	Unit Weight in Water (t/m^3)	Remark
Km 5	$Cv = 0.1355Z + 0.25$	0	0.7	Silty
Km 17.6	$= 0.099Z + 2.235$	0	0.7	Silty
Km 25.2	$= 0.1425Z + 2.0$	0	0.7	Silty
Km 35.2	$= 0.285Z + 2.5$	0	0.7	Silty up to −20 m
	$= 0$	35	1.0	Sand

* Z ····· below datum (m)

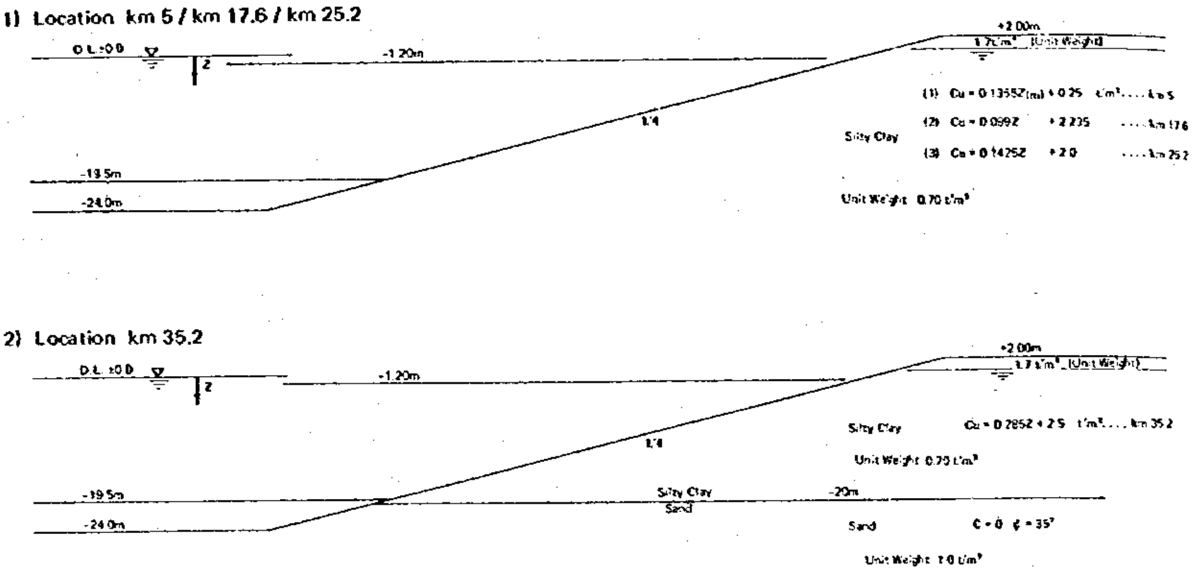


Fig. 8-4-11 Canal Section (for Circular Slip)

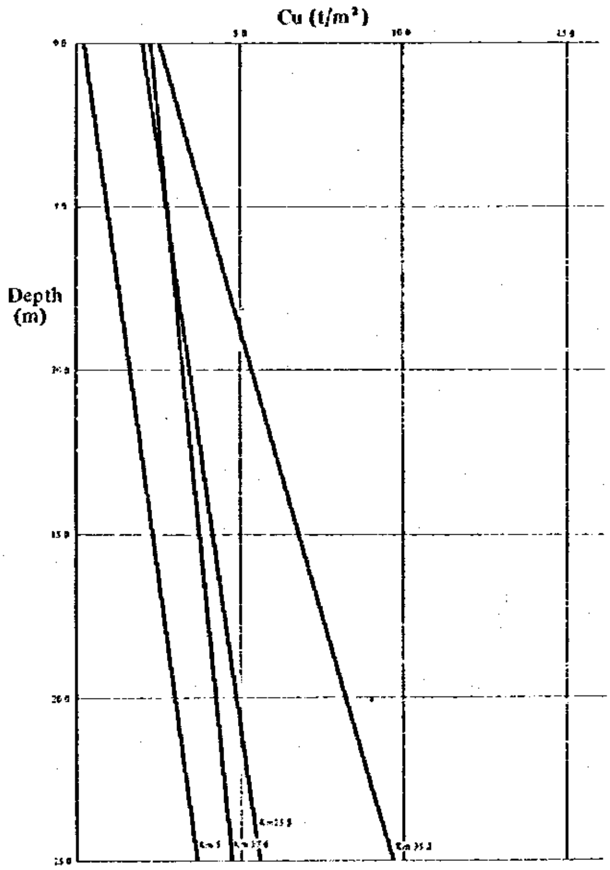


Fig. 8-4-12 Variation of q_u with depth

Table 8-4-2 Summary of Laboratory Tests Results

Sample No.	Natural Water Content	Dry Unit Weight (t/m^3)	Wet Unit Weight (t/m^3)	Grain size, Distribution Gravel (%)	Sand (%)	Fines (%)	Specific Gravity of Grains	Location (km)
1	65	1.02	1.67	0	0	100	2.67	23
2	70	0.92	1.62	0	0	100	2.69	23
3	47	1.24	1.71	0	1	99	2.71	7.7
4	106	0.67	1.73	0	13	87	2.67	19.5
5	83	0.83	1.66	14	8	78		19.5
6	31	1.52	1.84	0	10	90		19.5
7	77	0.91	1.68	0	0	100		19.5
8	64	1.00	1.64	0	0	100		17.6
		Average	1.69					

Source: Kotzias-Stamatopoulos

(2) Results of computation

The results of computation are shown in Fig. 8-4-13 (a) through (j) and also in Table 8-4-3 (a) through (j). Minimum safety factors are as shown below.

Minimum Safety Factors

Water depth / Location	Km 5	Km 17.6	Km 25.2	Km 35.2
–19.5m	0.89 (1.70)	1.85	2.19	3.18
–24.0m	0.92 (1.68)	1.78	2.14	3.14

The figures in brackets show the safety factor of a cross-section with a berm against the failure at the toe of slope.

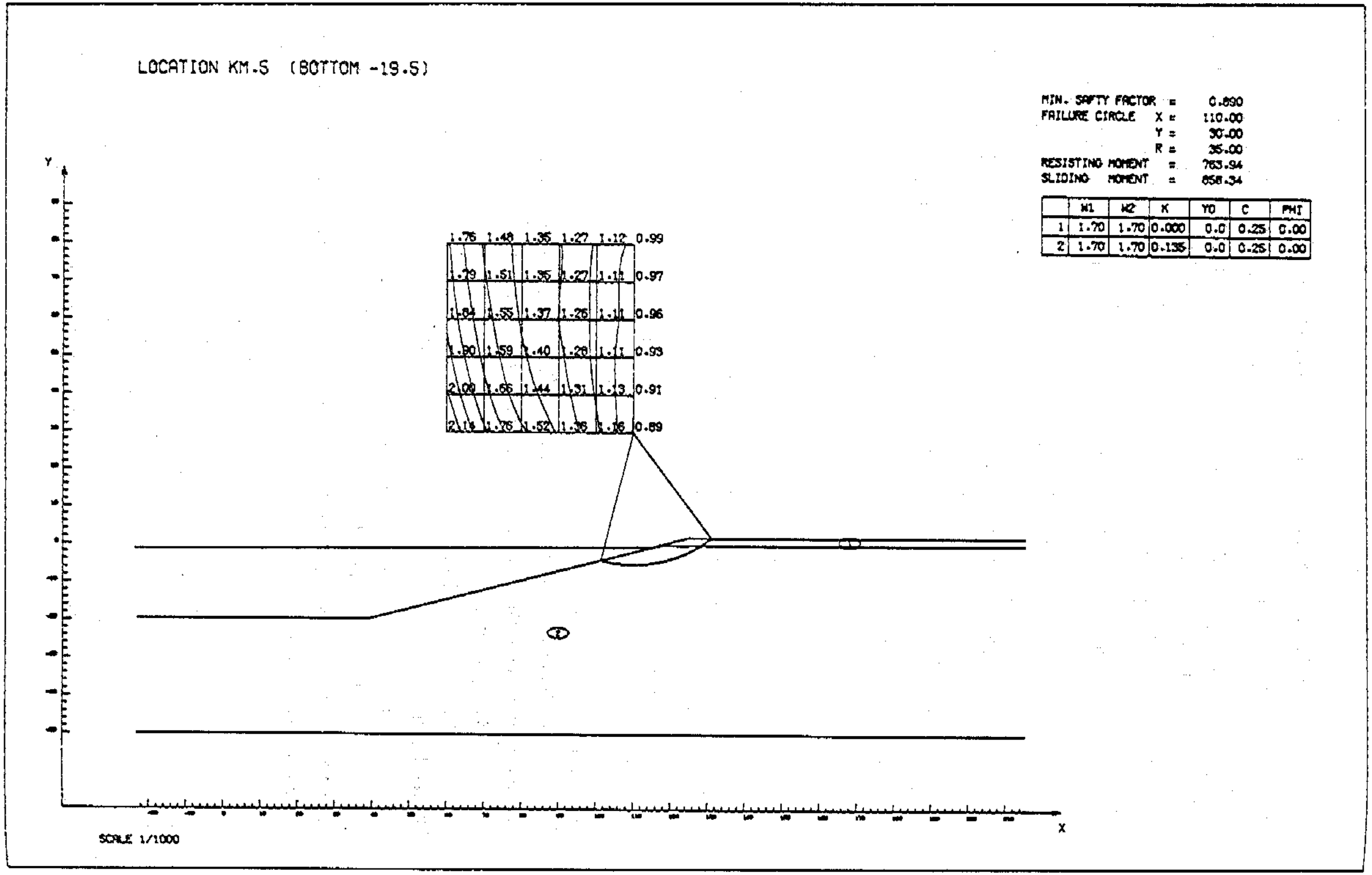


Fig. 8-4-13 (a) Circular Slip

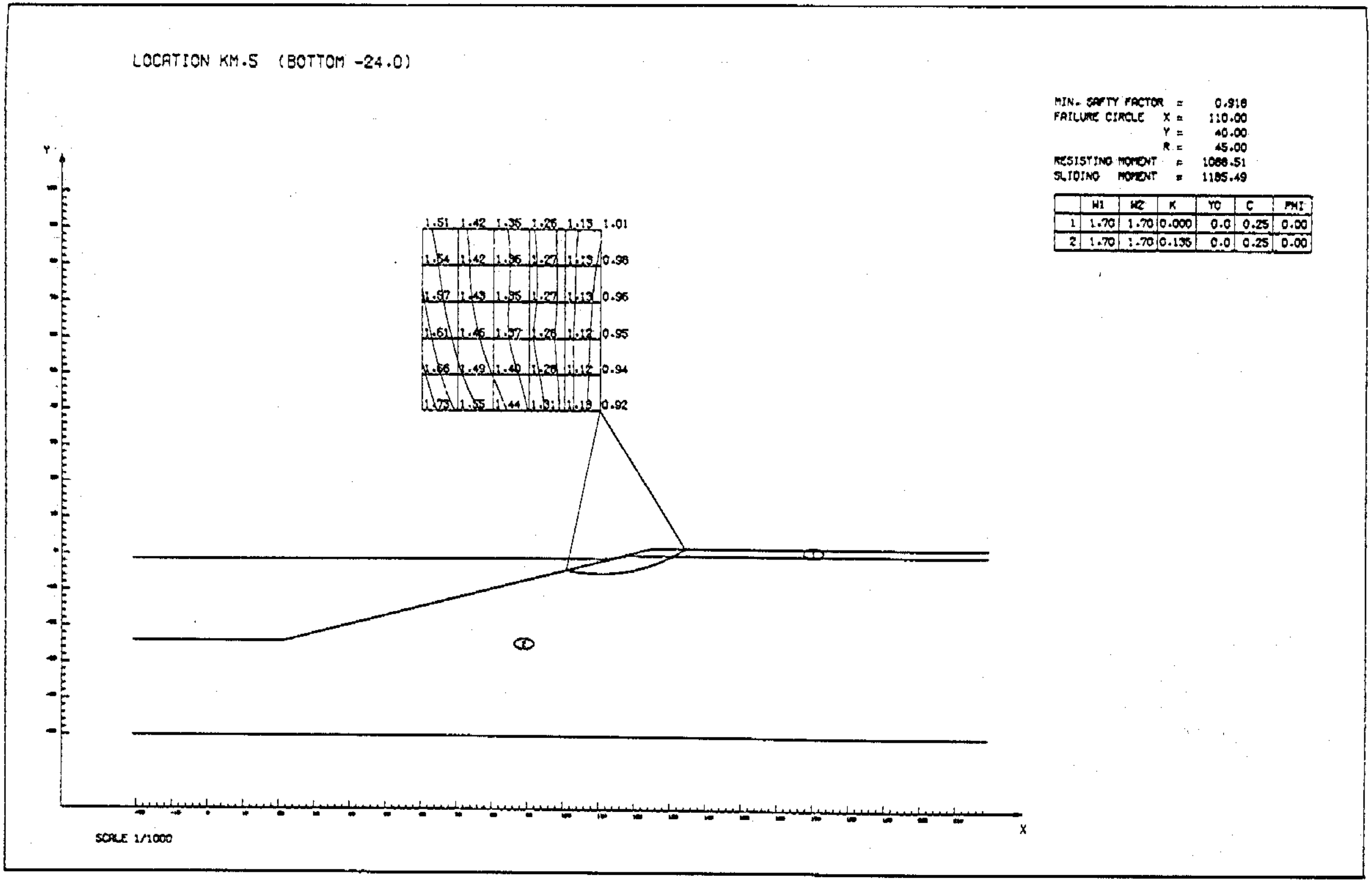
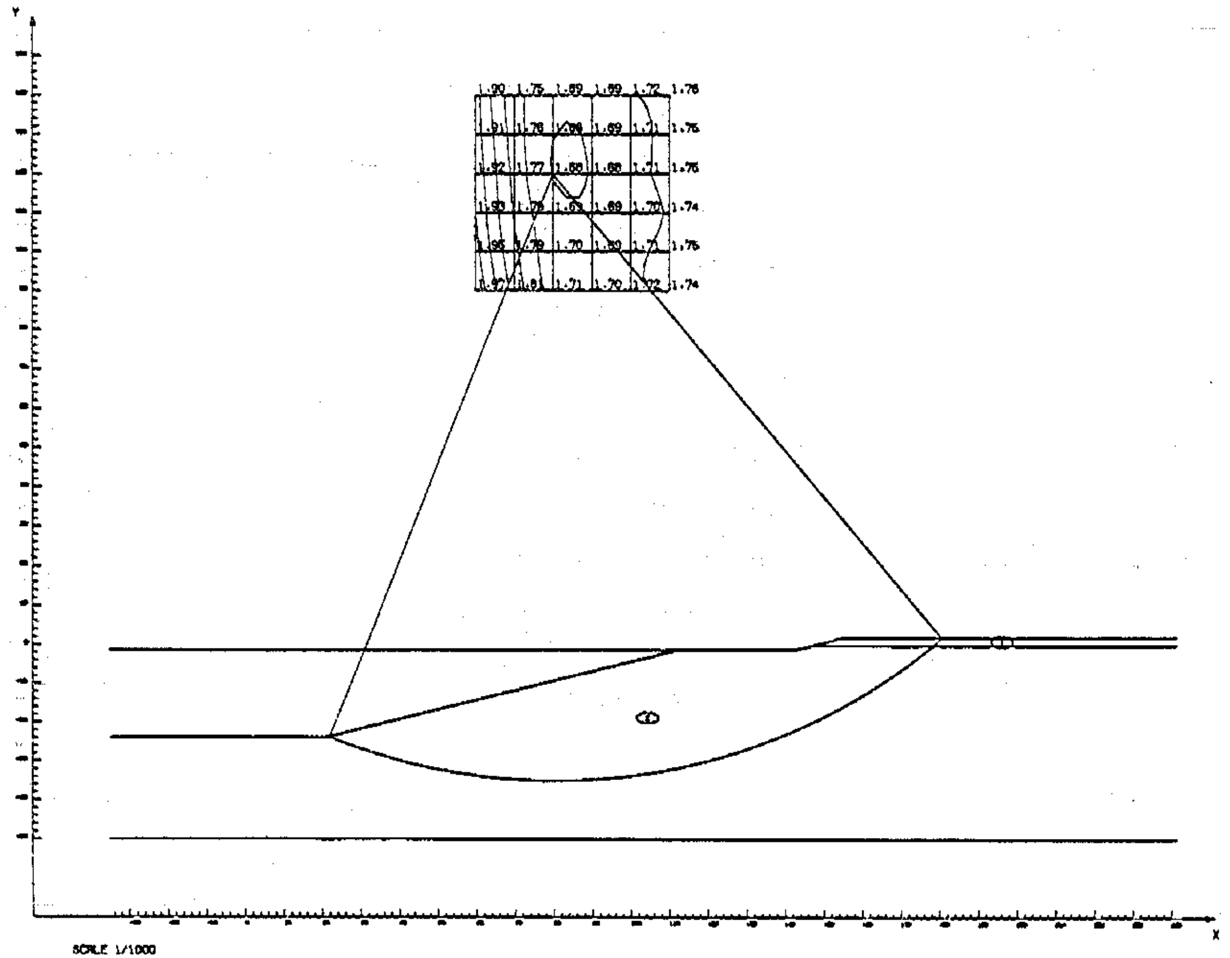


Fig. 8-4-13 (b) Circular Slip

LOCATION KM.5 (BOTTOM -24.0)



MIN. SAFTY FACTOR = 1.677
FAILURE CIRCLE X = 80.00
Y = 120.00
R = 165.00
RESISTING MOMENT = 97188.31
SLIDING MOMENT = 57931.98

	W1	W2	K	YO	C	PHI
1	1.70	1.70	0.000	0.0	0.25	0.00
2	1.70	1.70	0.135	0.0	0.25	0.00

Fig. 8-4-13 (c) Circular Slip

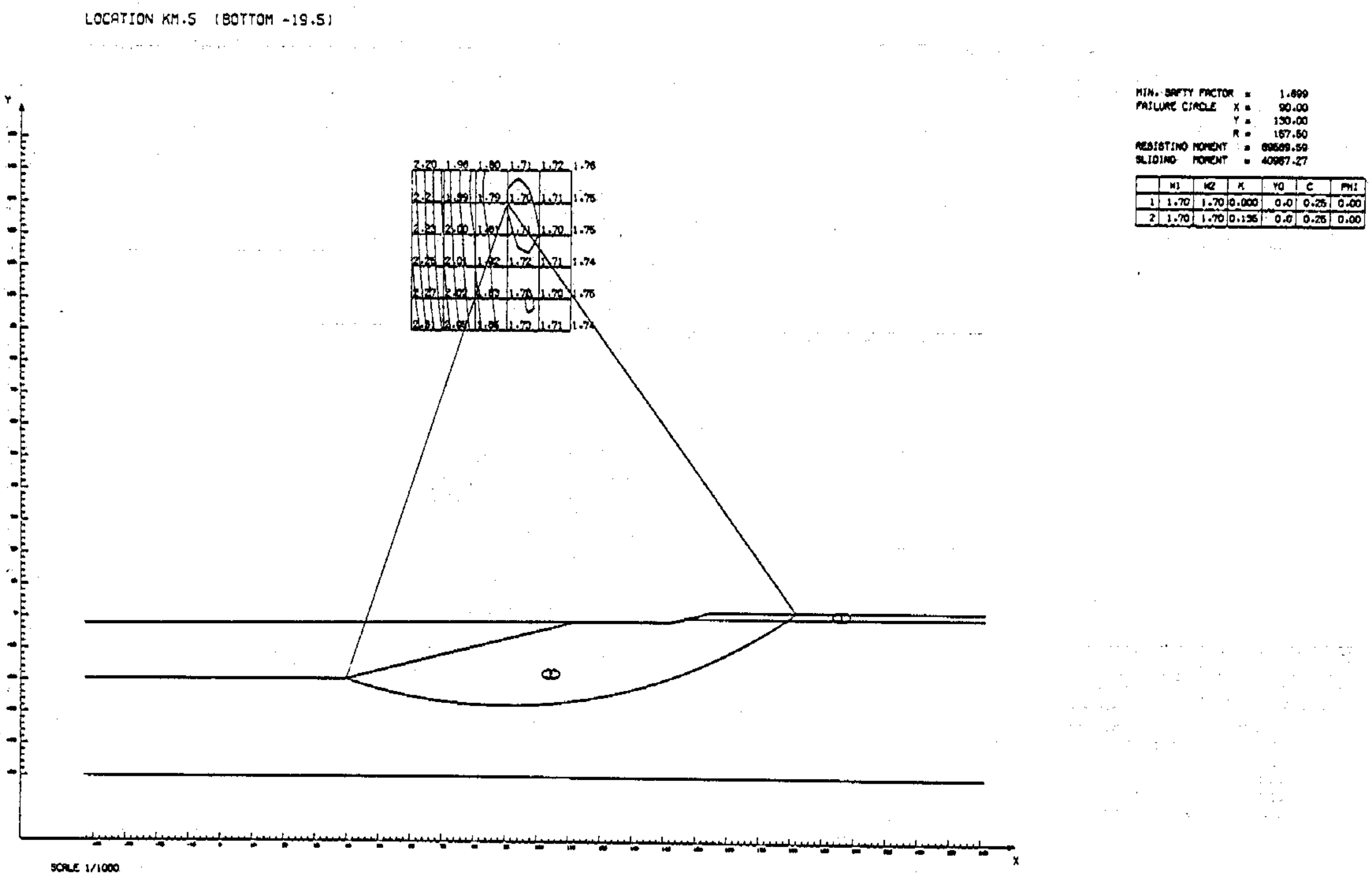


Fig. 8-4-13 (d) Circular Slip

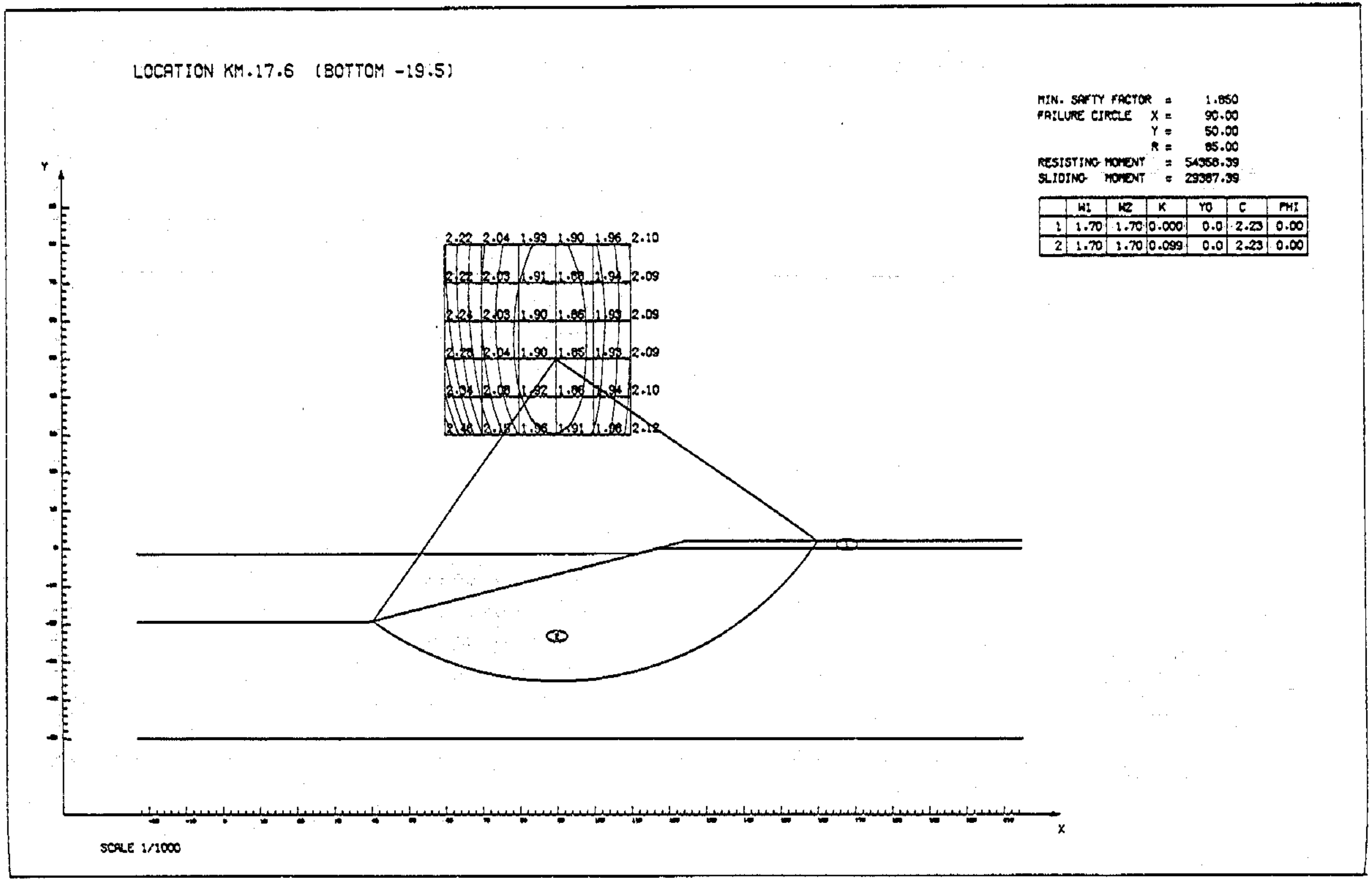


Fig. 8-4-13 (c) Circular Slip

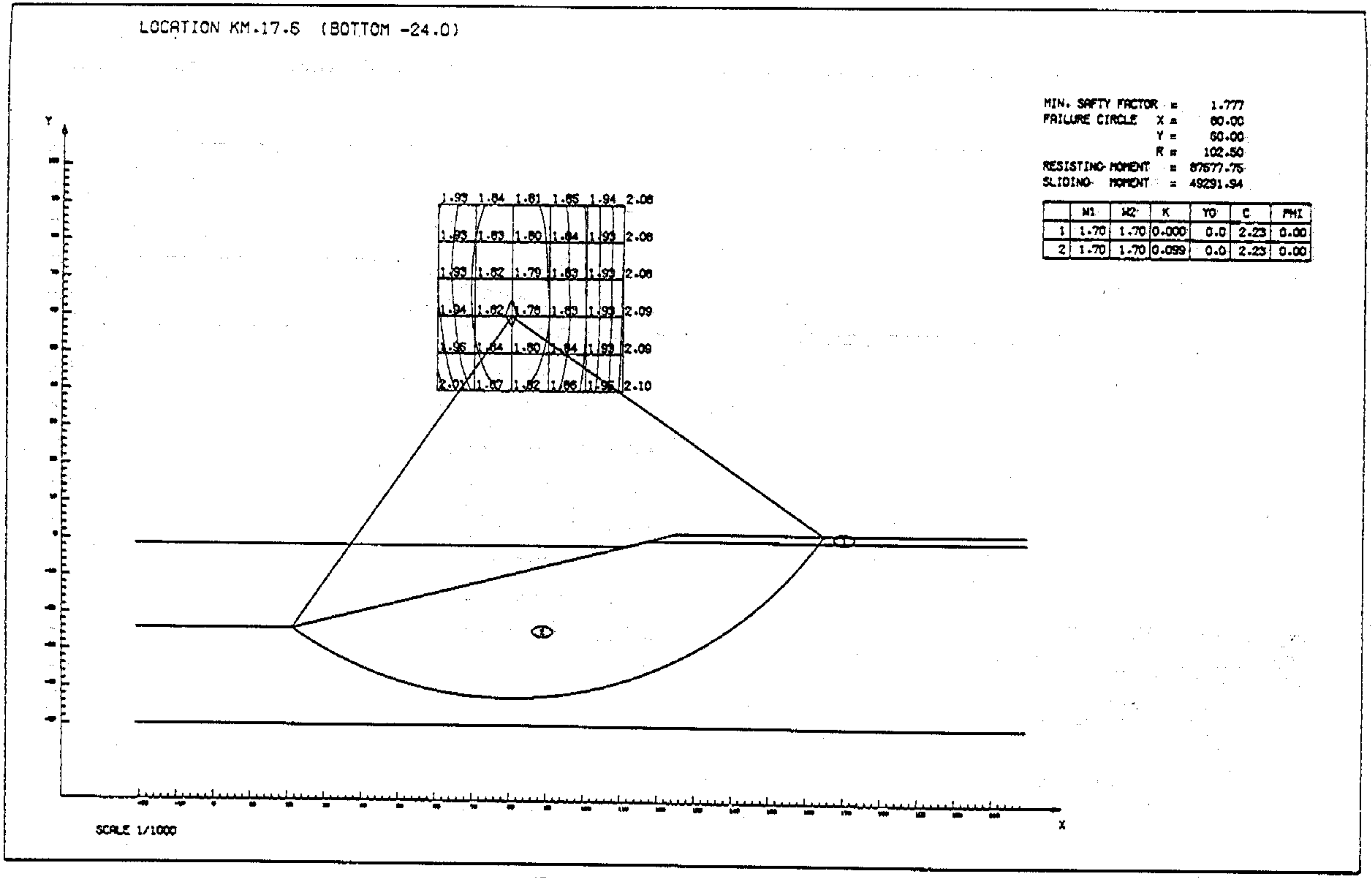


Fig. 8-4-13 (f) Circular Slip

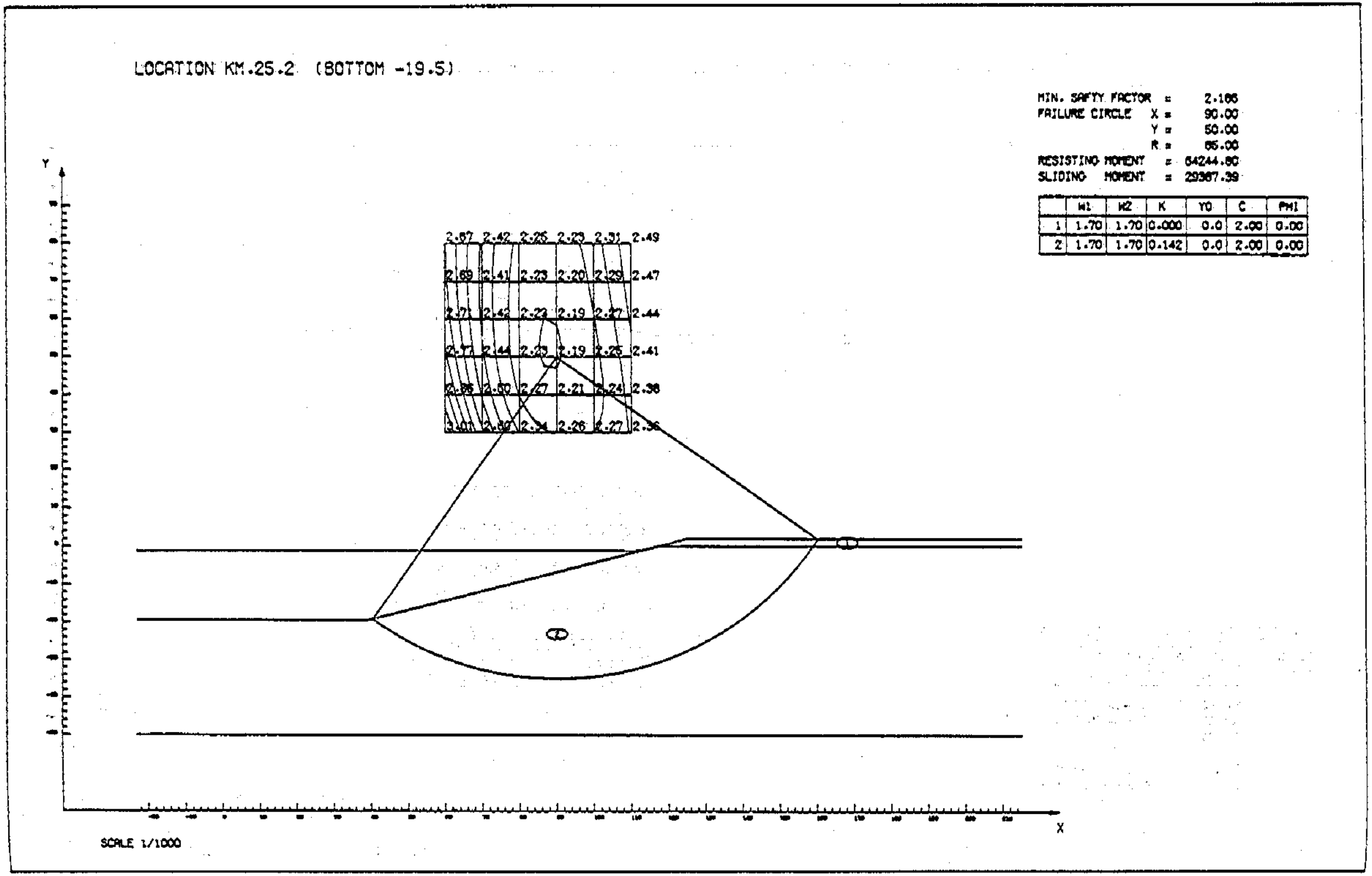
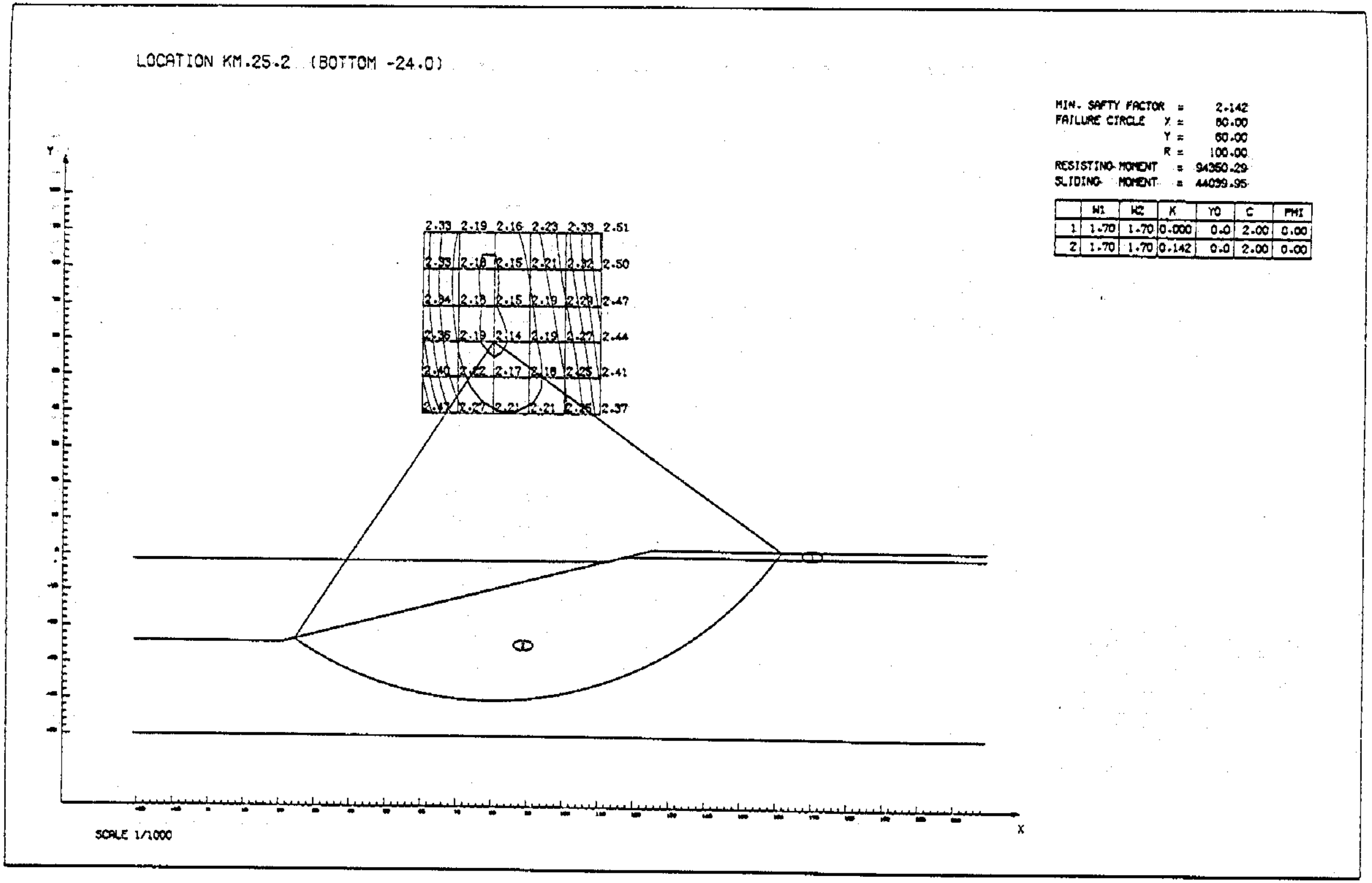
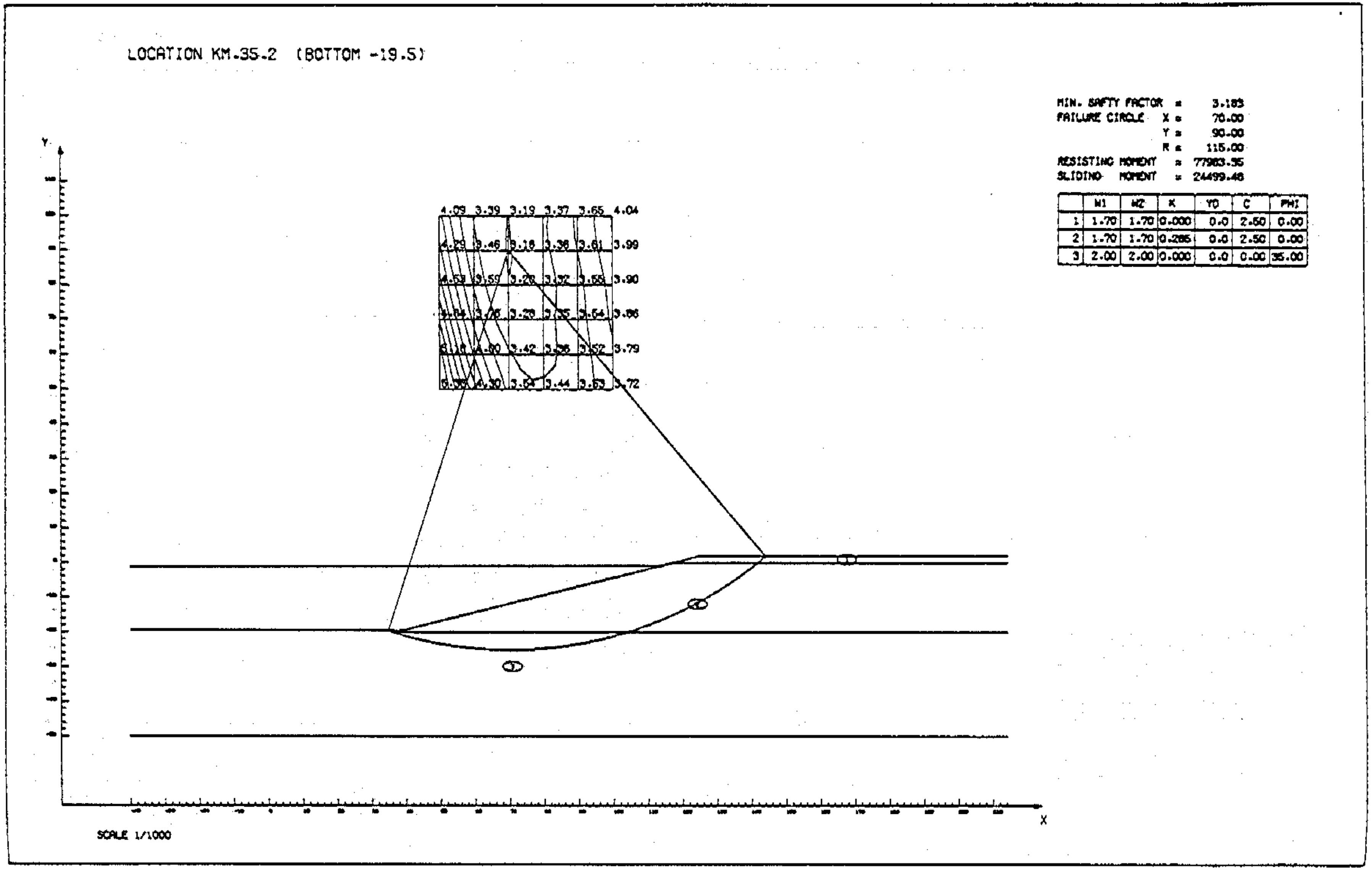


Fig. 8-4-13 (g) Circular Slip



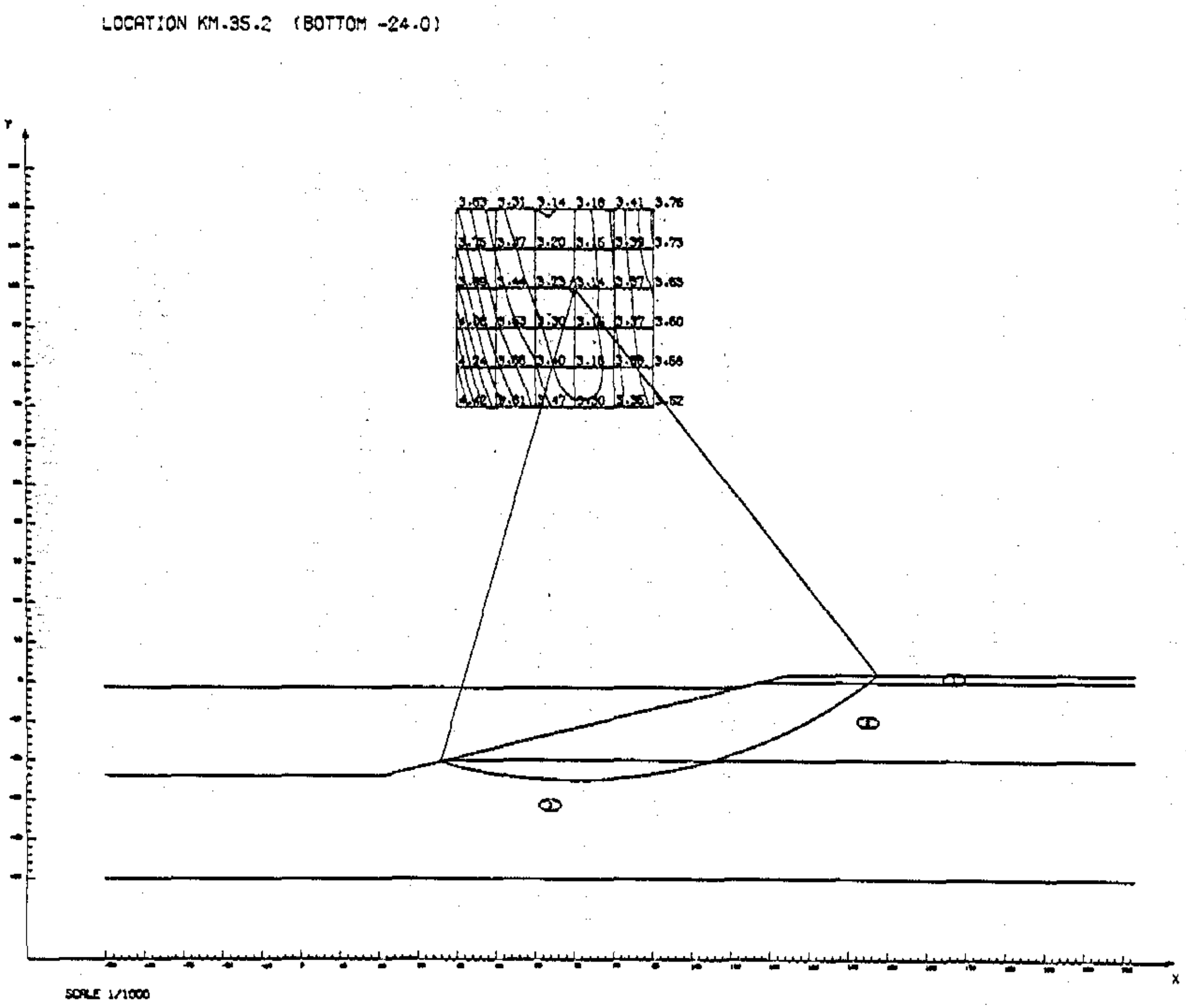
	W1	W2	K	YO	C	PHI
1	1.70	1.70	0.000	0.0	2.00	0.00
2	1.70	1.70	0.142	0.0	2.00	0.00

Fig. 8-4-13 (h) Circular Slip



	W1	W2	K	YO	C	PHI
1	1.70	1.70	0.000	0.0	2.50	0.00
2	1.70	1.70	0.285	0.0	2.50	0.00
3	2.00	2.00	0.000	0.0	0.00	35.00

Fig. 8-4-13 (i) Circular Slip



MIN. SAFTY FACTOR = 3.137
FAILURE CIRCLE X = 70.00
Y = 100.00
R = 125.00
RESISTING MOMENT = 88311.03
SLIDING MOMENT = 28149.68

	W1	W2	K	YO	C	PHI
1	1.70	1.70	0.000	0.0	2.50	0.00
2	1.70	1.70	0.286	0.0	2.60	0.00
3	2.00	2.00	0.000	0.0	0.00	36.00

Fig. 8-4-13 (j) Circular Slip

LOCATION KM.5 (BOTTOM -19.5)

***** MINIMUM SAFTY FACTOR LIST *****

Y	X= 60.00	70.00	80.00	90.00	100.00	110.00	MINIMUM
80.00	1.7624	1.4846	1.3520	1.2635	1.1244	.9929	.9929
70.00	1.7938	1.5100	1.3543	1.2663	1.1100	.9686	.9686
60.00	1.8373	1.5457	1.3687	1.2571	1.1124	.9551	.9551
50.00	1.9022	1.5918	1.3965	1.2823	1.1095	.9332	.9332
40.00	1.9370	1.6589	1.4382	1.3125	1.1291	.9106	.9106
30.00	2.1377	1.7636	1.5247	1.3648	1.1633	.8900	.8900
MINIMUM	1.7624	1.4846	1.3520	1.2571	1.1095	.8900	.8900

MINIMUM SAFTY FACTOR = .8900

XC = 110.00 RESISTING MOMENT = 763.94
YC = 30.00 SLIDING MOMENT = 858.34
R = 35.00

Table 8-4-3 (a) Circular Slip

LOCATION KM.5 (BOTTOM -24.0)

***** MINIMUM SAFTY FACTOR LIST *****

Y	X= 60.00	70.00	80.00	90.00	100.00	110.00	MINIMUM
90.00	1.5104	1.4157	1.3529	1.2571	1.1272	1.0067	1.0067
80.00	1.5434	1.4237	1.3563	1.2680	1.1251	.9835	.9835
70.00	1.5703	1.4348	1.3546	1.2657	1.1259	.9592	.9592
60.00	1.6076	1.4600	1.3651	1.2552	1.1176	.9452	.9452
50.00	1.6593	1.4932	1.3963	1.2825	1.1246	.9356	.9356
40.00	1.7346	1.5456	1.4434	1.3136	1.1307	.9182	.9182
MINIMUM	1.5104	1.4157	1.3529	1.2552	1.1176	.9182	.9182

MINIMUM SAFTY FACTOR = .9182

XC = 110.00 RESISTING MOMENT = 1088.51
YC = 40.00 SLIDING MOMENT = 1185.49
R = 45.00

Table 8-4-3 (b) Circular Slip

LOCATION KM.5 (BOTTOM -19.5)

***** MINIMUM SAFTY FACTOR LIST *****

Y	X= 60.00	70.00	80.00	90.00	100.00	110.00	MINIMUM
140.00	2.2027	1.9829	1.7953	1.7084	1.7175	1.7571	1.7084
130.00	2.2138	1.9861	1.7902	1.6987	1.7053	1.7485	1.6987
120.00	2.2270	1.9959	1.8120	1.7066	1.7004	1.7463	1.7004
110.00	2.2478	2.0056	1.8204	1.7160	1.7081	1.7370	1.7081
100.00	2.2741	2.0237	1.8328	1.7181	1.7017	1.7459	1.7017
30.00	2.3121	2.0491	1.8493	1.7346	1.7084	1.7394	1.7084
MINIMUM	2.2027	1.9829	1.7902	1.6987	1.7004	1.7370	1.6987

MINIMUM SAFTY FACTOR = 1.6987

XC = 90.00 RESISTING MOMENT = 69589.59
YC = 130.00 SLIDING MOMENT = 40967.27
R = 157.50

Table 8-4-3 (c) Circular Slip

LOCATION KM.5 (BOTTOM -24.0)

***** MINIMUM SAFTY FACTOR LIST *****

Y	X= 60.00	70.00	80.00	90.00	100.00	110.00	MINIMUM
140.00	1.9007	1.7516	1.6944	1.6879	1.7211	1.7591	1.6879
130.00	1.9066	1.7569	1.6814	1.6852	1.7075	1.7524	1.6814
120.00	1.9158	1.7660	1.6772	1.6825	1.7093	1.7504	1.6772
110.00	1.9301	1.7762	1.6950	1.6860	1.7000	1.7367	1.6860
100.00	1.9470	1.7909	1.7027	1.6891	1.7140	1.7464	1.6891
90.00	1.9733	1.8103	1.7115	1.7001	1.7170	1.7428	1.7001
MINIMUM	1.9007	1.7516	1.6772	1.6825	1.7000	1.7367	1.6772

MINIMUM SAFTY FACTOR = 1.6772

XC = 80.00 RESISTING MOMENT = 97166.31
YC = 120.00 SLIDING MOMENT = 57931.93
R = 155.00

Table 8-4-3 (d) Circular Slip

LOCATION KM.17.6 (BOTTOM -19.5)

***** MINIMUM SAFTY FACTOR LIST *****

Y	X= 60.00	70.00	80.00	90.00	100.00	110.00	MINIMUM
80.00	2.2179	2.0422	1.9322	1.9008	1.9535	2.0954	1.9008
70.00	2.2200	2.0312	1.9112	1.8795	1.9388	2.0877	1.8795
60.00	2.2384	2.0283	1.8974	1.8634	1.9290	2.0878	1.8634
50.00	2.2750	2.0442	1.8954	1.8497	1.9331	2.0931	1.8497
40.00	2.3376	2.0774	1.9153	1.8644	1.9449	2.1006	1.8644
30.00	2.4561	2.1509	1.9643	1.9107	1.9757	2.1166	1.9107
MINIMUM	2.2179	2.0283	1.8954	1.8497	1.9290	2.0877	1.8497

MINIMUM SAFTY FACTOR = 1.8497

XC = 90.00 RESISTING MOMENT = 54358.39
YC = 50.00 SLIDING MOMENT = 29387.39
R = 85.00

Table 8-4-3 (e) Circular Slip

LOCATION KM.17.6 (BOTTOM -24.0)

***** MINIMUM SAFTY FACTOR LIST *****

Y	X= 60.00	70.00	80.00	90.00	100.00	110.00	MINIMUM
90.00	1.9330	1.8422	1.8114	1.8458	1.9385	2.0808	1.8114
80.00	1.9253	1.8285	1.7958	1.8362	1.9329	2.0793	1.7958
70.00	1.9261	1.8218	1.7886	1.8334	1.9338	2.0846	1.7886
60.00	1.9371	1.8231	1.7767	1.8292	1.9303	2.0865	1.7767
50.00	1.9625	1.8371	1.7956	1.8400	1.9347	2.0912	1.7956
40.00	2.0108	1.8696	1.8233	1.8616	1.9451	2.0985	1.8233
MINIMUM	1.9253	1.8218	1.7767	1.8292	1.9303	2.0793	1.7767

MINIMUM SAFTY FACTOR = 1.7767

XC = 80.00 RESISTING MOMENT = 87577.75
YC = 60.00 SLIDING MOMENT = 49291.94
R = 102.50

Table 8-4-3 (f) Circular Slip

LOCATION KM.25.2 (BOTTOM -19.5)

***** MINIMUM SAFTY FACTOR LIST *****

Y	X= 60.00	70.00	80.00	90.00	100.00	110.00	MINIMUM
80.00	2.6726	2.4198	2.2503	2.2269	2.3147	2.4946	2.2269
70.00	2.6861	2.4112	2.2342	2.1983	2.2896	2.4686	2.1983
60.00	2.7141	2.4181	2.2290	2.1916	2.2666	2.4466	2.1916
50.00	2.7671	2.4437	2.2305	2.1861	2.2501	2.4076	2.1861
40.00	2.8631	2.4991	2.2659	2.2092	2.2437	2.3808	2.2092
30.00	3.0118	2.6039	2.3434	2.2631	2.2710	2.3582	2.2631
MINIMUM	2.6726	2.4112	2.2290	2.1861	2.2437	2.3582	2.1861

MINIMUM SAFTY FACTOR = 2.1861

XC = 90.00 RESISTING MOMENT = 64244.80
YC = 50.00 SLIDING MOMENT = 29387.39
R = 85.00

Table 8-4-3 (g) Circular Slip

LOCATION KM.25.2 (BOTTOM -24.0)

***** MINIMUM SAFTY FACTOR LIST *****

Y	X= 60.00	70.00	80.00	90.00	100.00	110.00	MINIMUM
90.00	2.3309	2.1944	2.1648	2.2277	2.3338	2.5085	2.1648
80.00	2.3297	2.1812	2.1468	2.2063	2.3193	2.4974	2.1468
70.00	2.3352	2.1822	2.1486	2.1925	2.2937	2.4688	2.1486
60.00	2.3576	2.1945	2.1424	2.1860	2.2700	2.4392	2.1424
50.00	2.3977	2.2195	2.1655	2.1836	2.2503	2.4085	2.1655
40.00	2.4689	2.2706	2.2060	2.2092	2.2461	2.3739	2.2060
MINIMUM	2.3297	2.1812	2.1424	2.1836	2.2461	2.3739	2.1424

MINIMUM SAFTY FACTOR = 2.1424

XC = 80.00 RESISTING MOMENT = 94359.29
YC = 60.00 SLIDING MOMENT = 44039.95
R = 100.00

Table 8-4-3 (h) Circular Slip

LOCATION KM.35.2 (BOTTOM -19.5)

***** MINIMUM SAFTY FACTOR LIST *****

Y	X= 50.00	60.00	70.00	80.00	90.00	100.00	MINIMUM
100.00	4.0948	3.3883	3.1885	3.3667	3.6458	4.0418	3.1885
90.00	4.2942	3.4603	3.1831	3.3596	3.6116	3.9901	3.1831
80.00	4.5323	3.5873	3.1990	3.3225	3.5550	3.8963	3.1990
70.00	4.8448	3.7613	3.2787	3.3486	3.5403	3.8579	3.2787
60.00	5.1796	4.0021	3.4172	3.3581	3.5164	3.7856	3.3581
50.00	5.3628	4.3021	3.5432	3.4421	3.5265	3.7197	3.4421
MINIMUM	4.0948	3.3883	3.1831	3.3225	3.5164	3.7197	3.1831

MINIMUM SAFTY FACTOR = 3.1831

XC = 70.00 RESISTING MOMENT = 77983.35
YC = 90.00 SLIDING MOMENT = 24499.48
R = 115.00

Table 8-4-3 (i) Circular Slip

LOCATION KM.35.2 (BOTTOM -24.0)

***** MINIMUM SAFTY FACTOR LIST *****

Y	X= 40.00	50.00	60.00	70.00	80.00	90.00	MINIMUM
120.00	3.6292	3.3080	3.1391	3.1815	3.4110	3.7603	3.1391
110.00	3.7472	3.3677	3.1997	3.1538	3.3915	3.7276	3.1538
100.00	3.8866	3.4400	3.2324	3.1372	3.3730	3.6320	3.1372
90.00	4.0592	3.5301	3.2979	3.1556	3.3681	3.5955	3.1556
80.00	4.2449	3.6563	3.3960	3.1589	3.3301	3.5809	3.1589
70.00	4.4200	3.8078	3.4699	3.2965	3.3508	3.5211	3.2965
MINIMUM	3.6292	3.3080	3.1391	3.1372	3.3301	3.5211	3.1372

MINIMUM SAFTY FACTOR = 3.1372

XC = 70.00 RESISTING MOMENT = 88311.03
YC = 100.00 SLIDING MOMENT = 28149.59
R = 125.00

Table 8-4-3 (j) Circular Slip

(3) Consideration

According to the present computation results, the canal banks at four sites considered have been found stable except the shoulder failure (Fs≐0.9) at Km 5. The safety factor of slip circle ranges from Fs=1.85 to 3.18 for the Canal water depth of −19.5m, and for the depth of −24.0m, Fs=1.78~3.14 have been obtained. Further, when a berm with the width of 50m and with the water depth of 1.20m is considered, the safety factor against the toe failure at Km 5 is improved to 1.70 for the case of −19.5m of the canal water depth or 1.68 for the case of −24.0m, and thus the slope becomes stable.

At Km 5, there is a possibility of small intra-slope failure near the slope shoulder because of low cohesion as shown in Fig. 8-4-12. The cohesion, particularly near the surface is only 1/10 of those at the other sites, as illustrated below:

Cu =	0.25 t/m^2	(Km 5)
=	2.235	(Km 17.6)
=	2.0	(Km 25.2)
=	2.5	(Km 35.2)

However, the center of the slip circle with a safety factor less than 1.0 is located on the upper part of the slope as seen from Fig. 8-4-13 (a). Therefore, it can be said that a large scale of failure will not occur. When the berm is provided, a toe failure with the minimum safety factor of 1.68 becomes the most critical as in the cases of the other sites. The safety factor is greater when the shallower water depth of the canal is less, but the difference is small and is not significant (Fig. 8-4-14). Further, the cohesion becomes better toward the southern part of the Canal resulting in increasing stability. For Km 5, it will be required to conduct more detailed soil surveys and clarify the characteristics of the soil near the surface.

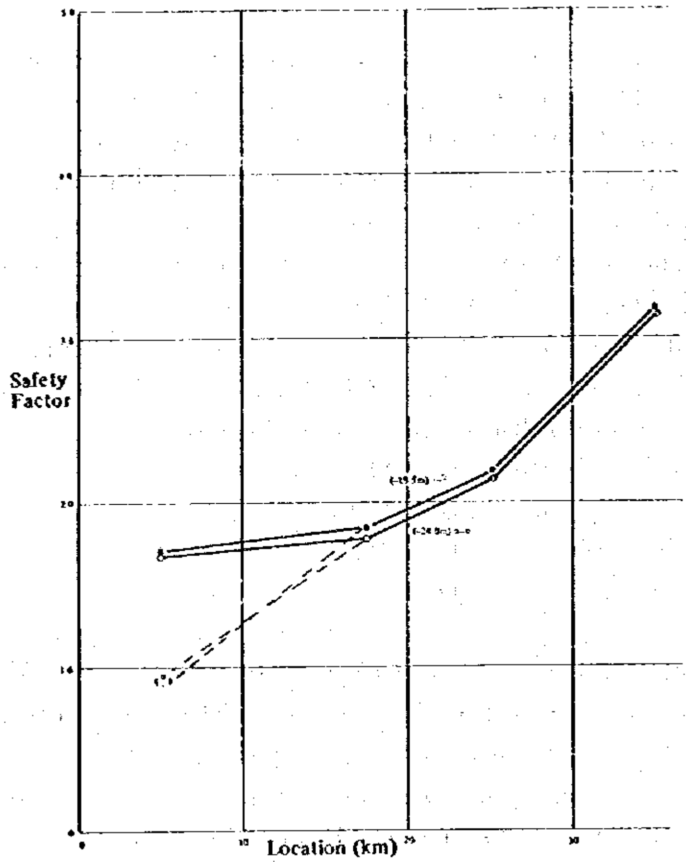


Fig. 8-4-14 Safety Factor versus Cu

5. Siltation in the Canal

The Canal and approach channel are subject to shoaling due to littoral drift. To secure the required water depth, maintenance dredging is carried out to periodically remove the deposited soil. A shoaling is caused by entirely different factors between canal and approach channel. A principal cause of shoaling in the Canal is the movement of water particles arising out of navigation of ships. Soil particles on the bank slope on each side of the Canal are displaced by the movement of water particles and fall down the bottom. To a slight degree, the wind-blown sand from the desert on both sides of the Canal is one of the causes of shoaling. On the other hand, the situation is different in the case of the approach channel located in open sea. In the approach channel, the cause of littoral drift is the movement of water particles due to waves and tidal currents, while the water disturbance due to navigation of ships is negligible.

To secure the required water depth of the channel is one of the most important problems. For formulating a maintenance dredging plan, it is required to know precisely the shoaling characteristics and the annual amount of siltation of the each section of the Canal. The theoretical estimate of the siltation with high accuracy is difficult since the hydraulic mechanism of littoral drift has not completely been clarified so far. Therefore the results of periodic soundings or the records of maintenance dredging volume at the site are usually used as an important factor for correcting the theoretical estimate.

Now, the quantities of maintenance dredging required for the canal at the First and Second Stages and the Master Plan will be examined.

5-1 Siltation Rate

Annual siltation rate at respective stages of development of the Canal will be theoretically examined for the canal as well as the approach channel. The movement of sediment in the canal is considered similar to that of sediment in rivers. Thus, the characteristics of siltation in the Canal will be estimated from the theory of sediment flow in river.

For calculation of the bed-load discharge in rivers, there are several formulas, but Sato, Yoshikawa and Ashida proposed the following formula.

$$q_B\,(\sigma/\rho-1)g/(\tau_o/\rho)^{3/2} = \psi F\,(\tau_o/\tau_c) \quad \cdots\cdots (19)$$

where $n \geqq 0.025$; $\psi = 0.623$ (n: Manning's roughness coefficient)

$n \leqq 0.025$; $\psi = 0.623\,(40n)^{-3.5}$

q_B : Bed-load discharge per unit width

σ : Specific gravity of sediment

ρ : Specific gravity of water

τ_o : Tractive force

τ_c : Critical tractive force

F : Function of τ_o/τ_c represented in Fig. 8-5-1

($\tau_c/\rho = 8.41\,d^{11/32}$ ..... $0.0065 \leqq d < 0.0565$ cm d: grain size) when $n = 0.025$, $\sigma = 2.65\ g/cm^3$ and $g = 980\ cm/sec^2$,

$\tau_o = \rho gRIe$, and

$I_e = n^2 V_r^2 / R^{4/3}$

where
R : Hydraulic radius
I_e : Energy gradient
V_r : Mean velocity of return current

$$q_B = \frac{1}{g(\sigma/\rho-1)} (g\, n^2 V_r^2/R^{1/3})^{3/2} \times 0.623 \times F(\tau_o/\tau_c)$$

$$= \frac{\sqrt{g}\, n^3}{(\sigma/\rho-1)\sqrt{R}} V_r^3 \times 0.623 \times F(\tau_o/\tau_c)\ (m^3/m/sec)$$

The discharge of bed load calculated by the above equation, though it does not give directly the volume of siltation on the canal bed, is very useful to understand the characteristics of siltation.

For calculating a bed load in river, several equations have been advocated and they are compared as shown in Fig. 8-5-2. From the figure, it is seen that the above equation gives rather smaller values than the others; in addition the differences among the equations are considerable. Therefore, the site survey is usually carried out on determining which equation is the most suitable to the peculiar condition of each site.

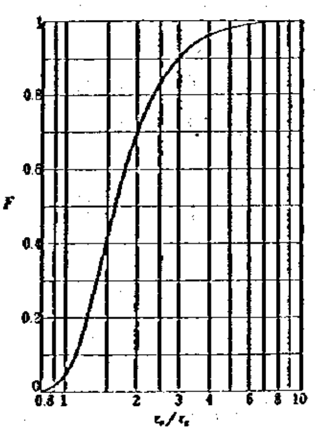


Fig. 8-5-1 F-versus $\tau o/\tau c$

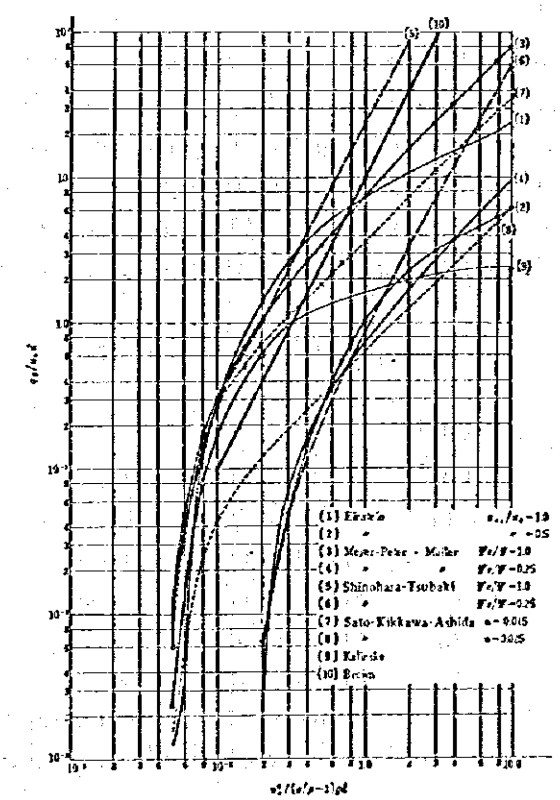


Fig. 8-5-2 Comparison of Equations for Bed Load

For the Suez Canal, with its long reach and great variety of soil characteristics, it is extremely difficult to establish an accurate method for the estimate of siltation rate, especially for the section composed of silt. Further study is needed for accurate estimates including periodic soundings.

In Fig. 8-5-3 and Table 8-5-1 are shown the discharge of bed load calculated by equation (19), for the canal section of bank slope 1/3 and grain size 0.1m/m.

The cross sections are those proposed in Parts for the Second Stage and the Master Plan, while the ship sizes are by equations (6) ~ (11). A bed load increases with a increasing ship speed and size. Of the characteristics illustrated in the Fig. 8-5-3, the critical ship speed which does not produce any appreciable bed load is of great interest. Fig. 8-5-3 (d) shows the critical ship speed for siltation at each Stage. The speed of laden tanker causing a negligible bed load are :

In the case of a ballast tanker, the hull resistance in a restricted channel is not so serious, and it can transit at a higher speed. However, this undoubtedly will cause more siltation.

When an allowable rate of siltation is taken at 1.5 times that of laden tanker considering the lower transit frequency of large ballast tanker, the maximum transit speed of a ballast tanker is given at about 14km/h by equation (19) as below.

$$Vs = \sqrt[3]{1.5}\ \frac{13\,(4.6-1)}{(4.8-1)} = 14.1\ \mathrm{km/h}$$

Where,

	Area Ratio	Ship Speed	Siltation Rate
Laden Tanker	4.8	13 km/h	1.0
Ballast Tanker	4.6	Vs	1.5

9 km/h	130,000 DWT	Second Stage
12 km/h	100,000 DWT	Second Stage
10 km/h	300,000 DWT	Master Plan
13 km/h	200,000 DWT	Master Plan

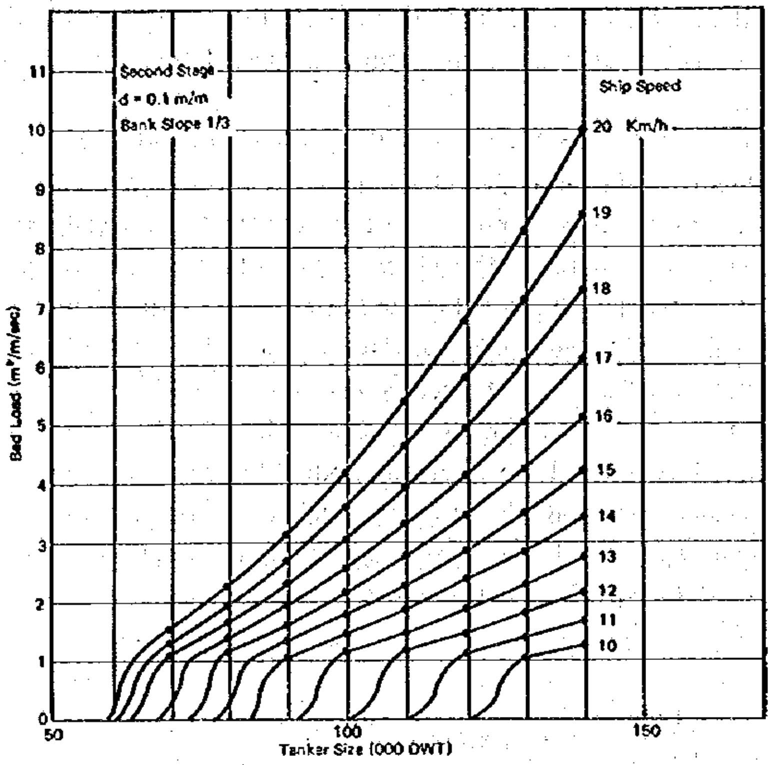


Fig. 8-5-3 (a) Bed Load by Return Current ($m^3/m/sec.$)

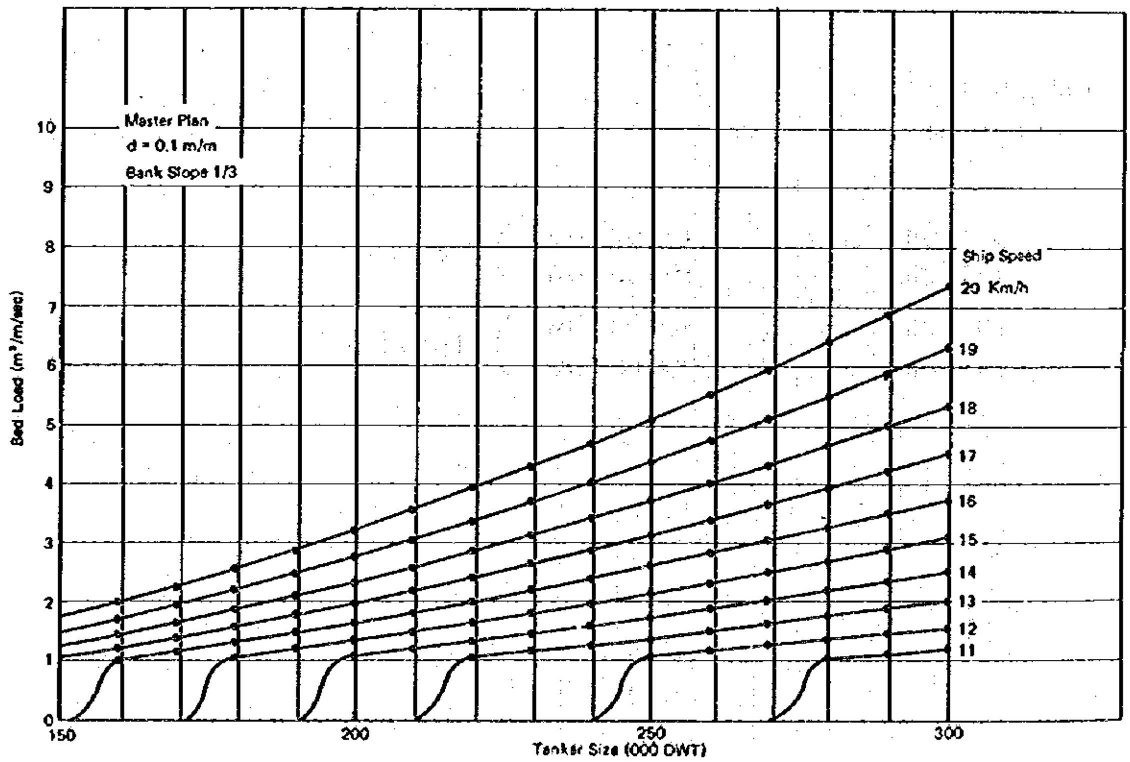


Fig. 8-5-3 (b) Bed Load by Return Current ($m^3/m/sec.$)

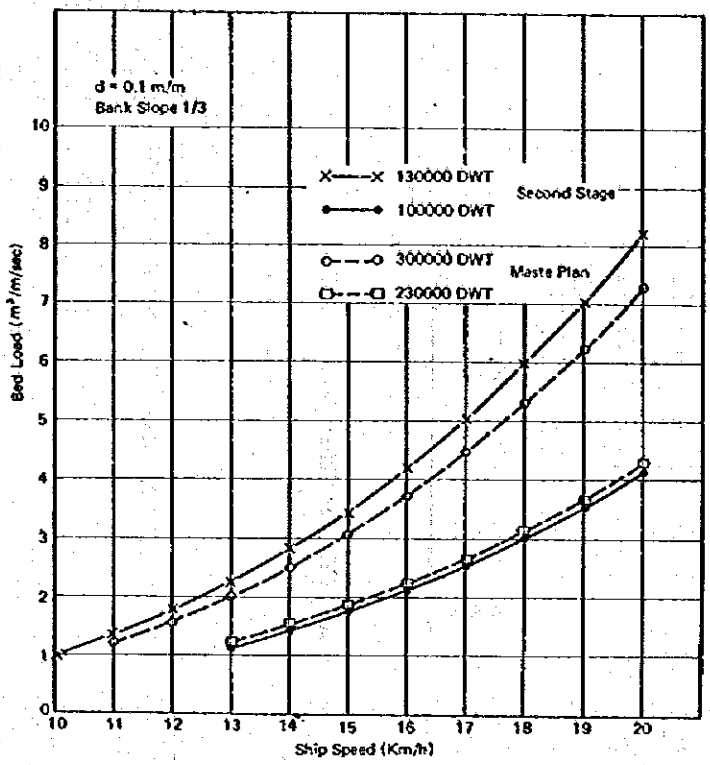


Fig. 8-5-3 (c) Bed Load by Return Current ($m^3/m/sec$)

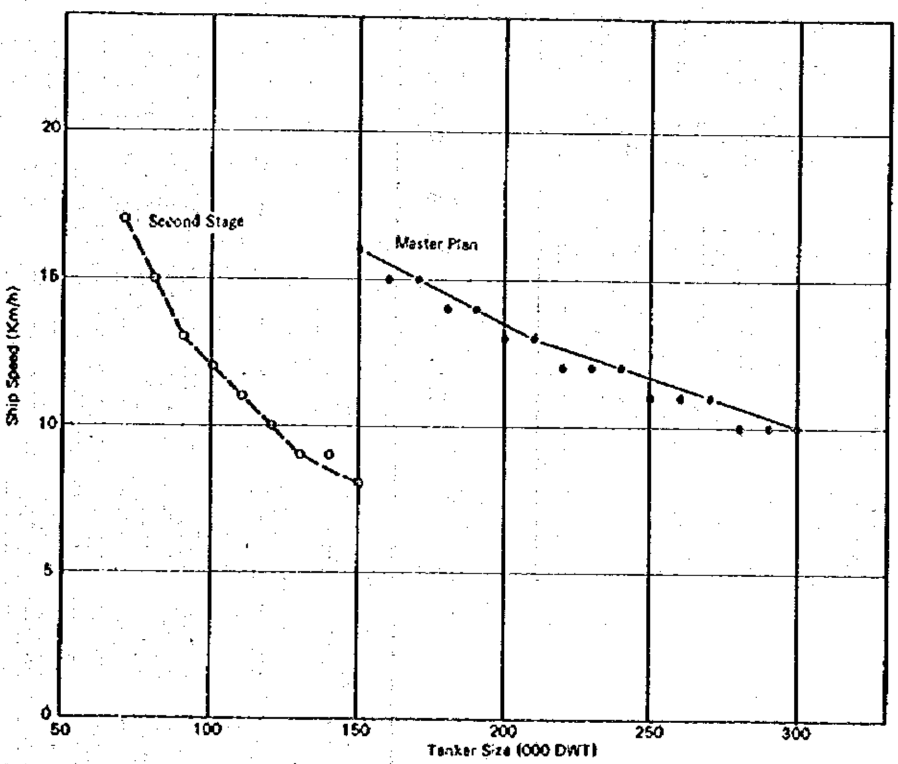


Fig. 8-5-3 (d) Ship Speed with No Bed Load

Table 8-5-1 (a) Bed Load by Return Current (m^3/m/sec) (Second Stage)

170.0+00 Canal Width (m)
3.000+00 Bank Slope
100.0-03 Grain Size (m/m)

Ship Size (DWT)	50.00+03	60.00+03	70.00+03	80.00+03	90.00+03	100.0+03	110.0+03	120.0+03	130.0+03	140.0+03	150.0+03
V_s = 5 km/h	0.	0.	0.	0.	0.	354.5-12	5.537-09	16.97-09	33.25-09	61.26-09	97.62-09
6	0.	0.	0.	0.	6.116-09	22.12-09	50.45-09	90.73-09	140.3-09	196.2-09	256.4-09
7	0.	0.	401.3-12	11.94-09	40.16-09	87.45-09	149.5-09	220.9-09	298.2-09	380.7-09	468.3-09
8	0.	0.	12.45-09	49.59-09	113.2-09	194.6-09	286.5-09	386.0-09	492.8-09	607.7-09	731.4-09
9	0.	7.317-09	44.62-09	118.9-09	217.2-09	329.8-09	450.9-09	583.8-09	728.3-09	886.9-09	1.059-06
10	424.8-12	25.94-09	101.4-09	212.3-09	341.9-09	485.2-09	644.9-09	821.0-09	1.015-06	1.229-06	1.462-06
11	7.239-09	64.41-09	178.6-09	322.5-09	485.5-09	668.8-09	874.7-09	1.105-06	1.361-06	1.644-06	1.953-06
12	22.58-09	119.3-09	270.3-09	447.6-09	650.7-09	882.6-09	1.146-06	1.442-06	1.773-06	2.139-06	2.540-06
13	49.48-09	187.8-09	373.8-09	589.4-09	840.9-09	1.132-06	1.464-06	1.840-06	2.259-06	2.724-06	3.233-06
14	88.62-09	266.3-09	487.9-09	750.2-09	1.060-06	1.420-06	1.833-06	2.302-06	2.825-06	3.405-06	4.041-06
15	138.4-09	353.2-09	616.1-09	932.8-09	1.310-06	1.751-06	2.259-06	2.834-06	3.478-06	4.191-06	4.974-06
16	196.5-09	448.6-09	759.4-09	1.139-06	1.594-06	2.129-06	2.744-06	3.443-06	4.224-06	5.089-06	6.040-06
17	261.0-09	553.4-09	919.5-09	1.372-06	1.916-06	2.556-06	3.295-06	4.132-06	5.069-06	6.108-06	7.248-06
18	331.2-09	668.6-09	1.098-06	1.632-06	2.278-06	3.037-06	3.913-06	4.927-06	6.020-06	7.253-06	8.607-06
19	407.1-09	795.2-09	1.296-06	1.923-06	2.681-06	3.574-06	4.605-06	5.774-06	7.083-06	8.533-06	10.12-06
20	488.9-09	934.4-09	1.516-06	2.243-06	3.129-06	4.171-06	5.373-06	6.737-06	8.264-06	9.956-06	11.81-06

Table 8-5-1 (b) Bed Load by Return Current (m^3/m/sec) (Master Plan)

240.0+00 Canal Width (m)
3.000+00 Bank Slope
100.0-03 Grain Size (m/m)

Ship Size (DWT)	150.0+03	160.0+03	170.0+03	180.0+03	190.0+03	200.0+03	210.0+03	220.0+03	230.0+03	240.0+03	250.0+03	260.0+03	270.0+03	280.0+03	290.0+03	300.0+03
V_s = 5 km/h	0.	0.	0.	0.	0.	0.	0.	0.	729.6-12	2.203-09	4.162-09	6.669-09	9.780-09	13.54-09	17.99-09	23.14-09
6	0.	0.	0.	1.238-09	3.625-09	7.017-09	11.56-09	17.38-09	24.53-09	33.04-09	42.88-09	53.99-09	66.27-09	79.61-09	93.88-09	109.0-09
7	2.398-09	6.372-09	12.25-09	20.32-09	30.69-09	43.35-09	58.19-09	74.98-09	93.45-09	113.3-09	134.4-09	156.3-09	179.0-09	202.2-09	226.0-09	250.1-09
8	20.38-09	33.76-09	50.73-09	70.99-09	94.03-09	119.3-09	146.3-09	174.7-09	204.0-09	234.1-09	264.9-09	296.2-09	328.0-09	360.3-09	393.1-09	426.4-09
9	62.84-09	90.07-09	120.8-09	154.1-09	189.4-09	225.9-09	263.5-09	302.0-09	341.3-09	381.3-09	422.1-09	463.7-09	506.3-09	549.3-09	593.4-09	638.4-09
10	131.1-09	171.9-09	215.0-09	259.8-09	305.9-09	353.2-09	401.6-09	451.2-09	501.9-09	553.9-09	607.2-09	661.9-09	717.7-09	775.1-09	833.8-09	893.9-09
11	218.4-09	271.2-09	325.9-09	382.2-09	440.2-09	499.8-09	561.2-09	624.4-09	689.6-09	756.6-09	825.7-09	896.7-09	969.7-09	1.045-06	1.122-06	1.201-06
12	319.3-09	384.5-09	451.8-09	521.6-09	593.8-09	668.6-09	745.0-09	826.2-09	909.8-09	994.7-09	1.083-06	1.174-06	1.268-06	1.365-06	1.464-06	1.566-06
13	432.8-09	512.0-09	594.5-09	680.5-09	770.0-09	863.2-09	960.1-09	1.061-06	1.165-06	1.273-06	1.385-06	1.500-06	1.619-06	1.741-06	1.867-06	1.996-06
14	559.9-09	655.9-09	756.5-09	861.9-09	972.1-09	1.087-06	1.207-06	1.332-06	1.461-06	1.596-06	1.734-06	1.878-06	2.026-06	2.179-06	2.336-06	2.497-06
15	702.5-09	818.3-09	940.3-09	1.069-06	1.203-06	1.344-06	1.492-06	1.643-06	1.802-06	1.967-06	2.137-06	2.314-06	2.496-06	2.683-06	2.876-06	3.075-06
16	862.6-09	1.002-06	1.149-06	1.303-06	1.465-06	1.635-06	1.813-06	1.998-06	2.190-06	2.390-06	2.597-06	2.811-06	3.032-06	3.259-06	3.494-06	3.735-06
17	1.042-06	1.207-06	1.383-06	1.567-06	1.762-06	1.965-06	2.178-06	2.400-06	2.632-06	2.870-06	3.118-06	3.374-06	3.639-06	3.912-06	4.193-06	4.482-06
18	1.243-06	1.438-06	1.645-06	1.864-06	2.094-06	2.335-06	2.588-06	2.851-06	3.125-06	3.409-06	3.703-06	4.008-06	4.322-06	4.646-06	4.980-06	5.323-06
19	1.466-06	1.695-06	1.938-06	2.195-06	2.466-06	2.749-06	3.046-06	3.356-06	3.678-06	4.012-06	4.359-06	4.716-06	5.085-06	5.467-06	5.860-06	6.253-06
20	1.713-06	1.990-06	2.263-06	2.567-06	2.879-06	3.209-06	3.555-06	3.916-06	4.292-06	4.681-06	5.085-06	5.507-06	5.934-06	6.379-06	6.837-06	7.308-06

5-2 Maintenance Dredging

As the mechanism of littoral drift has not yet been sufficiently clarified, it is dangerous to apply the foregoing to quantitative forecast of siltation. Thus, the annual siltation along the extension of the canal was assumed to be 1,200,000 m^3, from the records of the quantities of siltation and spoil of maintenance dredging. It can be assumed that this is proportional to the number of ships transiting the Canal.

This may be rather excessive because the increased area ratio causes a decreased velocity in the return current and this is expected to reduce the siltation rate.

Further, the siltation of the Port Said approach channel was calculated with the thickness of annual shoaling assumed from the results of past studies as below:

Depth	Siltation
–14m	40 cm
–20m	15 cm

The forecasted values of siltation in the canal and the approach channel are shown in Table 8-5-2. These values were calculated upon the assumption that the quantity of siltation would be a result of the return current due to navigation of ships only. With the influence of the tidal current taken into consideration, the siltation in the expanded canal section will increase considerably. And its characteristic should be studied from the results of observation to be conducted hereafter at the site.

Not only to design the optimum channel section and layout but also to set out the adequate maintenance dredging plan, a further study is needed on the following items.

1) Observation of wind, wave and tidal current
2) Periodical sounding, (twice a year at least, and after stormy weather)
3) Sampling of bed soil and suspended load (same frequency as the above)
4) Trial dredging and its monitoring survey..

To cover item i), the team has included in the plans a bouy at the entrance of Port Said approach channel equipped with a telemetric transfer system of weather and sea conditions. The data obtained are also very useful for controlling transit of ships.

Of the above, a trial dredging is of a great importance by which accurate estimate of maintenance dredging volume can be possible.

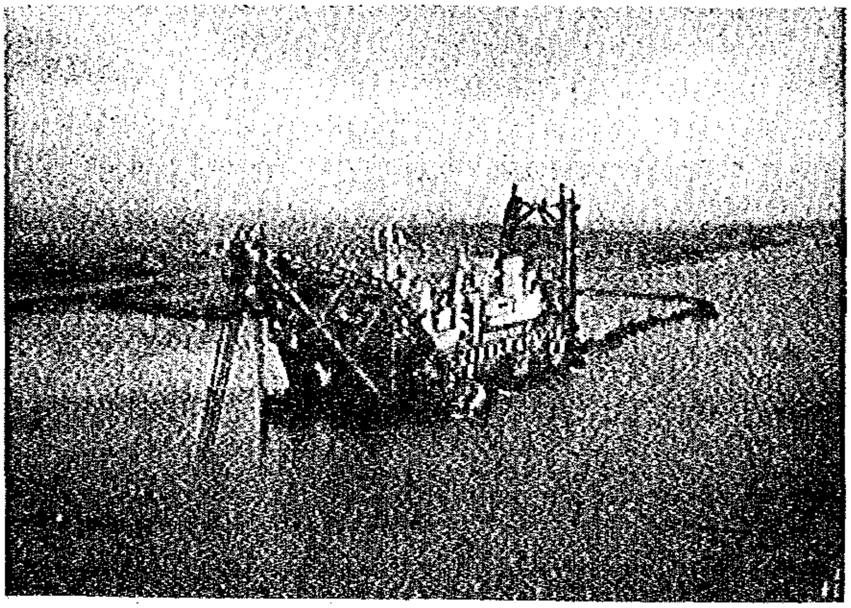
The same thing can be applied to the canal itself, but in addition the records of the velocity of the tidal current and tidal level are required. Further, both experimental and theoretical analysis are imperative for better understanding of the complicated phenomena of siltation which is dependent largely on the peculiar conditions of each site.

The extension of Port Said Breakwaters, for instance, could well be decided based on the results of the above analysis.

Table 8-5-2 Maintenance Dredging Volume

($10^3 m^3$)

Section \ Case	Existing	Plan 0	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5
~ Km 0	2,780	2,780	2,780	2,780	2,780	2,780	2,780
Km 0 ~ Km 61	830	930	1,070	1,110	1,190	1,260	2,850
Km 61 ~ Km 162	410	460	530	550	590	620	1,410



IX. Implementation

PART IX. IMPLEMENTATION

1. Outline of Work

1-1 Dry excavation

The volume of dry excavation is about 226 x $10^6 m^3$, and it is about 2.5 times the volume under the First Stage Project, because the work for this consists of the excavation of the whole width of the new channel, on which the soil of dry excavation and dredging under the First Stage Project has been dumped.

The dumping distance of soil is somewhat longer than that of the First Stage Project. It is 1.5 times the First Stage Project for the channel developed on the west side and about 2 times for the east side. The unit cost per unit volume in dry excavation is higher in proportion to the dumping distance. On the other hand, unit dredging cost by cutter suction dredger remains constant for a certain distance of dumping, but the dredging efficiency increases when dredging the whole section, and the unit dredging cost will come down for that portion.

Accordingly, the difference of unit costs between dry excavation and dredging in the Second Stage Project is smaller compared with that in the First Stage Project. Further, for the section where the dredging efficiency is high, the unit cost of dredging is lower than that of dry excavation.

The volume of soil to be dry excavated is about 50 x $10^6 m^3$ in the section between Km 16 and Km 52, about 100 x $10^6 m^3$ in the section between Km 58 and Km 92, and about 80 x $10^6 m^3$ in the section between Km 134 and Km 161. The unit cost of dredging is lower than that of dry excavation in the section between Km 16 and Km 52, while the unit cost of both works is nearly the same for the section between Km 58 and Km 92, and dry excavation is cheaper in the section between Km 134 and Km 161.

The unit costs are estimated on the basis of the works in the First Stage Project and the working conditions in the Second Stage Project, and are subject to change due to the supply and demand conditions of materials, the market situation etc. For the section where the unit cost of dry excavation is higher than that of dredging, a dry excavation should be replaced by a dredging work. However, a dry excavation is to be executed by a local contractor using about 90% local currency, while a dredging work is carried out by a foreign contractor using about 85% foreign currency. Therefore, a dry excavation can be chosen in preference of using local contractors for the political considerations of foreign exchange balances, even if the unit cost of it is slightly higher.

1-2 Bank work

The total length of new revetment under the Second Stage Project will be about 220 Km, 1.5 times the work of the First Stage Project. The extension under Phase I will be only 135 Km, and the work period will be 4 years with an average working speed of 34 Km/year. This speed is almost the same to 35 Km/year of the First Stage Project, and then the speed of about one half of that under the Phase I will be enough for Phase II. Many kinds of construction methods and materials for the structure of revetment should be considered for safety and durability, but the construction cost will go up in any case. If the cost is limited, a similar structure to that under the First Stage Project shall be used. Some of the revetment constructed under the First Stage Project failed after the completion. The reason of the failures was judged to be due to the deficiency in the construction, because the revetment of the same structure has not been damaged in other places; thus special consideration must be taken for the management and inspection of construction to improve its reliability.

The revetment for the newly dredged channel is to be constructed on both sides, but there is a surplus space of 100 meter in front of the face line of the planned east revetment, until the east side revetment of the eastern channel is expanded to the sections under the Master Plan. A plan has been examined to leave it as is without constructing a revetment by utilizing the above mentioned surplus space, and providing a ditch to prevent the soil from falling down into the channel.

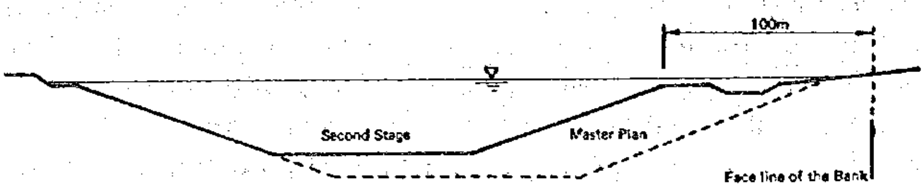


Fig. 9-1-1 Schematic Sketch of Eastern Bank

1-3 Dredging

The dredging work under the Second Stage Project consists mainly of a new channel dredging, starting areas are limited to those connected to the existing channel. Two or three vessels can be used on one site, but the optimum number is two for an efficient operation. Accordingly, the total number of dredgers depends on the number of available work sites, the work period should be determined by considering this condition.

The allotment of dredging sections for the SCA's own dredging fleet and contractor's fleet should be divided by considering the working conditions mentioned above. Therefore, the division of construction into small units or mixing of the sections into contract and SCAworks should be avoided. For instance, it is desirable to make one construction unit from the section between Km 72.5 and Km 94.5. If it is divided, it should be split into two sections of the same length. From these considerations, the SCA's fleet should be allotted preferentially to the section to the north of Km 52, where the work may be easy and continuous, and allotment of the construction of southern channel to contract work. In the Port Said and Suez approach channels, the work outside of Hm 50 of the Port Said Channel will be under the SCA and the other areas under contract.

1-4 Other works

Relocation of railways and roads is necessary at the section between Km 58 and Km 73.5 The dredged spoil in this section will be discharged to the Sinai Peninsula side, crossing the existing channel by a submerged pipeline, but the spoil of the dry excavation has to be dumped on the west side. Therefore, it is necessary to finish the relocation of railways and roads prior to the dry excavation. The lines to be relocated are kept not only from the new channel, but also from the pool area for the dumped spoil by dry excavation, so it is necessary to secure enough area for the pool. At the section between Km 134.5 and Km 145, the railways, roads and sweet water channels also should be relocated. The siphon supply of sweet water to the Sinai Peninsula, crossing the existing channel at the point of Km 92.8, can not stop during the construction, and the siphons passing through the new channel should be installed without any interruption of water supply.

1-5 Volume of works

The work volume under the Second Stage Project is as follows:

Table 9-1-1 Work Volume of Second Stage Project

Km	Dry Excavation	Bank Works		Dredging	Relocation		
	Volume	Removal	Con-struction	Volume	Railway	Road	Sweet water canal
	10^3m^3	km	km	10^3m^3	km	km	km
1.5 – 16.0		1.5	28.0	60,538			
16.0 – 32.5	14,000	1.5	28.0	67,913			
32.5 – 52.0	34,000	1.5	36.4	83,914			
58.0 – 73.5	37,000	2.4	31.0	54,669	19.0	19.0	
72.5 – 94.5	62,000	2.4	40.0	79,645			
94.5 – 134.5				43,182			
134.5 – 145.0	7,000	2.1	21.0	38,526	7.0	12.0	7.0
145.0 – 161.0	72,000	2.1	36.0	62,857			
Port Said Approach				46,109			
Suez Approach				18,475			
Total	226,000	13.5	220.4	555,828	26.0	31.0	7.0

The elevations separating the dry and dredging excavations are +2.0m for the section between Km 16 and Km 42, +1.0m from Km 42 to Km 145, and ±0m from Km 143.5 to Km 161.5 As an adequate topographical map is not presently available, the volume of dry excavation is estimated by assuming an average ground height from site observation, while the dredging volume is calculated from the section designed. Thus, considering the accuracy of calculations, the significant figures are set at 10^6m^3 for dry excavation and 10^3m^3 for dredging.

2. Implementation Plan

2-1 Dry excavation

The dry excavation will be executed by motor scraper (referred to as M.S.) The capacity and working conditions of an M.S. are as below:

Capacity of an M.S.	16 m^3
Excavation Modulus of an M.S.	70 %
Cycle Time	
Excavation of West Channel	6.3 min
Excavation of East Channel	7.5 min
Operation Hours per Day	7 hrs

Soil volume excavated by an M.S. per day is obtained as below;

$$16 \times \frac{70}{100} \times \frac{60}{6.3} \times 7 \div 750 m^3/day \text{ (West-side Channel)}$$

$$16 \times \frac{70}{100} \times \frac{60}{7.5} \times 7 \div 630 m^3/day \text{ (East-side Channel)}$$

The work period will be 5 years, 2.5 years and 3 years respectively to the dredging speed in each section, assuming the work is executed at the same time in the sections between Km 16 and Km 52, Km 58 and Km 73.5, and Km 72.5 and Km 94.5. From these times, the number of M.S. needed for this work will be 230. This figure is based on 25 working days per month and 7 working hours per day. In case of 2 shifts and 14 working hours per day, the necessary number of M.S. will be 115.

The excavation at the section between Km 135 and Km 161 in Phase II has a longer construction period as compared with the soil volume by dry excavation. So it will be possible to excavate using 80 M.S. working 7 hours per day.

2-2 Bank work

The revetment will be executed on dry work. The excavation will be executed by bulldozers and clamshells to the depth of −1.0m with the water drained by well pumps. Sheet piles will be placed by a diesel hammer pile driver, and stones and concrete blocks installed on the revetment. Assuming the works are to proceed as one unit, the capacity of execution for a unit should be determined by the capacity of sheet piling. If 20 sheet piles are placed per day with pile drivers, the capacity will be 8 m/day and 200 m/month with 25 working days. The revetment work should be executed at a higher speed than dredging. The average dredging speed will be 330 meters per month, if two of 10,000 HP dredgers owned by SCA are used on the section between Km 16 and Km 52. The speed under contracted work on the section between Km 58 and Km 73.5 will be 350 m/month by two of 8,000 HP dredgers, 270 m/month with a combination of a 8,000 HP and 4,000 HP dredger, and a speed of 330 meters with two of 8,000 HP dredgers on the section between Km 72.5 and Km 94.5. These figures are for dredging on one side only, and the pace of dredging performance using both sides will be double. The revetment work must be completed earlier than the dredging work, so 2 units for each side are necessary, in addition to starting construction well in advance of dredging.

2-3 Dredging

The monthly capacity of a cutter suction dredger is calculated under the following procedures:

a) Based on the dredging results of each LOT and dredger under the First Stage Project, the total days (divided into served days and periodical maintenance days), served days (divided into working days and resting days), working hours (divided into dredging hours and resting hours), resting items (machine repairs, relocation of ships, waiting for convoys, obstacles, change of cutters, holidays etc.), and volume of dredging are investigated.

b) The volume of soil dredged per hour, converted into the capacity of an 8,000 HP dredger in each LOT of the work (results from the First Stage Project) is calculated.

c) The monthly standard working hours under the Second Stage Project is determined after analysis of the monthly average working and resting hours of the First Stage Project.

d) The capacity of dredging is adjusted compared with the different dredging conditions in the shape of section, depth of dredging and nature of soil, between the First and Second Stages.

e) The monthly dredging volume of an 8,000 HP dredger is calculated by the hourly dredging volume, the monthly working hours and the correction coefficient of dredging efficiency for each Lot.

We can compare the Second Stage efficiency of dredging with the First Stage Project. Divided with the different channel and dredging characteristics, the total dredging efficiency of a Canal section depends on the working conditions, the size of channel to be dredged, and the soil hardness.

During the First Stage dredging, the working time loss due to waiting for convoys and relocation of dredgers totals 20 hours per month more than during the Second Stage. Thus, the Second Stage Project working efficiency will increase 4%.

The overall depth of channels dredged in the Second Stage is to be less than the First Stage. Amounting to a 4% increase in efficiency, this depth factor is a direct result of the 15% decrease in dredge pumping efficiency at depths from 15 to 20m. In addition, the deeper soil stratum is harder; this raises the efficiency of the shallower Second Stage dredging by 5%.

The new Canal Shape (section) in the Second Stage Project results in dredging efficiency to improve 10%. However, if instead the channel is to be widened 30 to 40m there is a drop in the efficiency 20%. The thickness of a soil layer to be dredged changes the efficiency; if a 1m thick slice is dredged, the efficiency drops 10%.

The 20 days per the first 5,000 working hours and 40 days per the next 5,000 hours are necessary for the periodical maintenance of dredger. The monthly soil volume dredged by the SCA is assumed less than that by dredgers of the contractors, considering the working hours per day, working days per month, periodical repairing period, working efficiency, the SCA dredger capacity of 10,000 PS against 8,000 PS of contractors, and the 75% of monthly dredging volume by contractors are taken into account. Two months per year are necessary for the periodical maintenance of the SCA dredgers.

The dredging work will be executed as follows:

The work will be conducted by two dredgers each working from both ends of each section of Km 16 and Km 52, Km 58 and Km 73.5 and Km 72.5 and Km 94.5 at the stage of Phase I. Of the above, the section between Km 16 and Km 52 is suitable for the SCA dredger.

The SCA owns six dredgers, consisting of four 10,000 HP with two operating presently and two under construction, and two 5,500 HP dredgers. For consideration of this work, one 10,000 HP dredger is sunk by accident, and one 5,500 HP dredger is old and thus considered taken out of this work. Thus the work will be proceeded with four dredgers, three each of 10,000 HP and one of 5,500 HP, and another two dredgers will work for the help to finish excavation and the maintenance. The working length at the section between Km 16 and Km 52 is longer and the work will be divided at the point Km 32.5 where the existing channel has been expanded. The two dredgers from the point Km 16 and other two dredgers from the point Km 32.5 to Port Said direction will pass through the section between Km 16 and Km 32.5, and will advance to the section between Km 32.5 and Km 52. At the section between Km 58 and Km 73.5, the work will be proceeded from the both ends by two dredgers (8,000 HP class and 4,000 HP class).

At the section between Km 72.5 and Km 94.5, the work will start at the both ends using one dredger (8,000 HP), another dredger (8,000 HP) will join on the way. The two dredgers joining later will have already completed the dredging at the section between Km 94.5 and Km 122.

During the dredging operation using two dredgers, they should be separated by at least 500m, with the first dredger removing an upper layer and the second taking the lower layer. 500 meters shall be the distance between the risting points of floating pipelines.

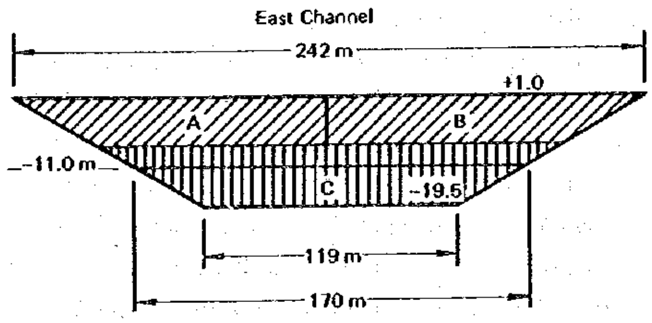


Fig. 9-2-1 Dredging of East Channel

The area of (A+B) is slightly larger than C. A,B,C are dredging blocks.

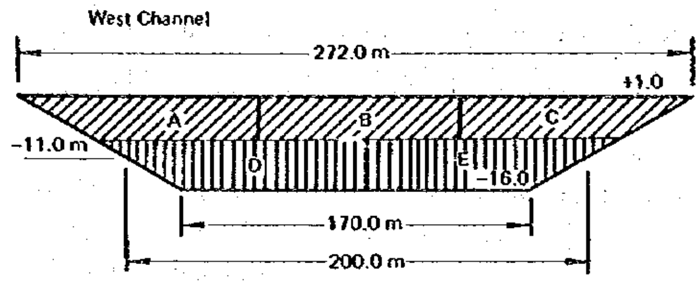


Fig. 9-2-2 Dredging of West Channel

A + B + C is slightly larger than D + E
A ~ E are dredging blocks.

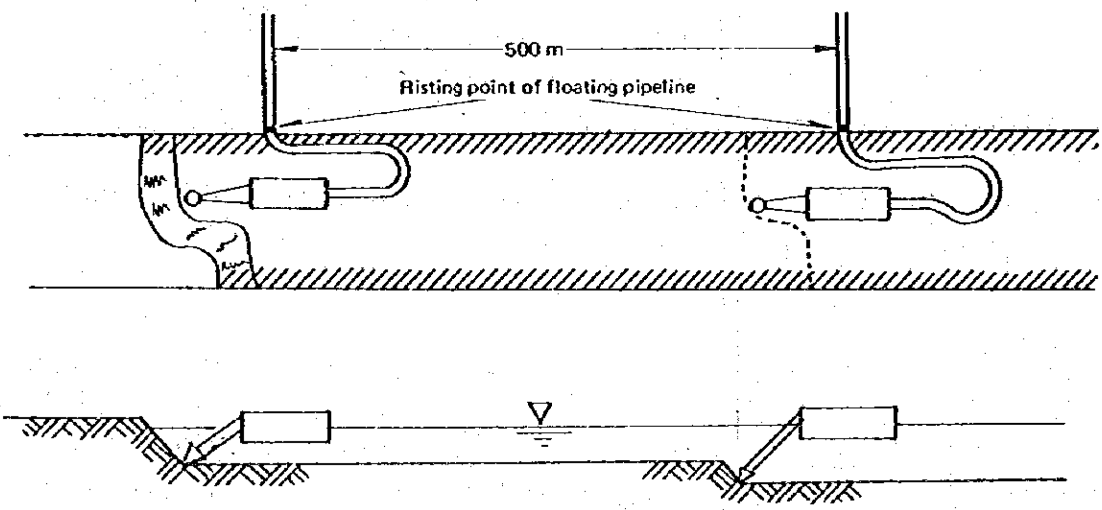


Fig. 9-2-3 Distance of Dredger

The dredging of the west channel at the section between Km 58 and Km 73.5 requires a submerged pipeline for crossing the existing channel, to dump the spoil to the east side.

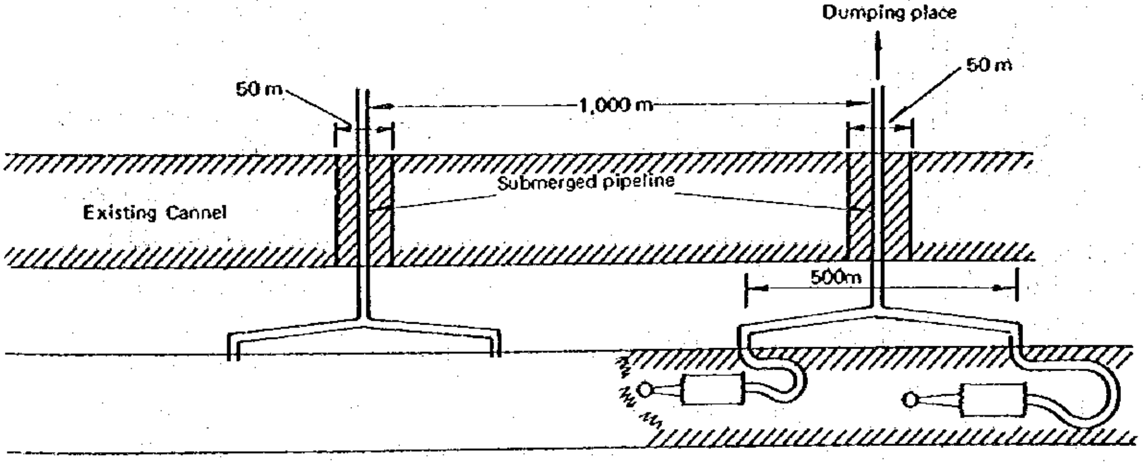


Fig. 9-2-4 Submerged Pipeline

The submerged pipeline should be installed in a ditch of 50 meter width and $-19.5 + (-1.5) = -21.0$ meter depth to keep the water depth of -19.5 meters in the existing channel.

2-4 Other works

The sweet water channel crossing at the point of Km 92.8 should supply water without interruption, even during the dredging time of the new channel. Therefore, the work should proceed on the mutual adjustment of dry excavation, dredging, installation of siphons, with consideration of the plan for expansion of the width and increase of the depth after the Second Stage.

The work process is shown in the following sketch:

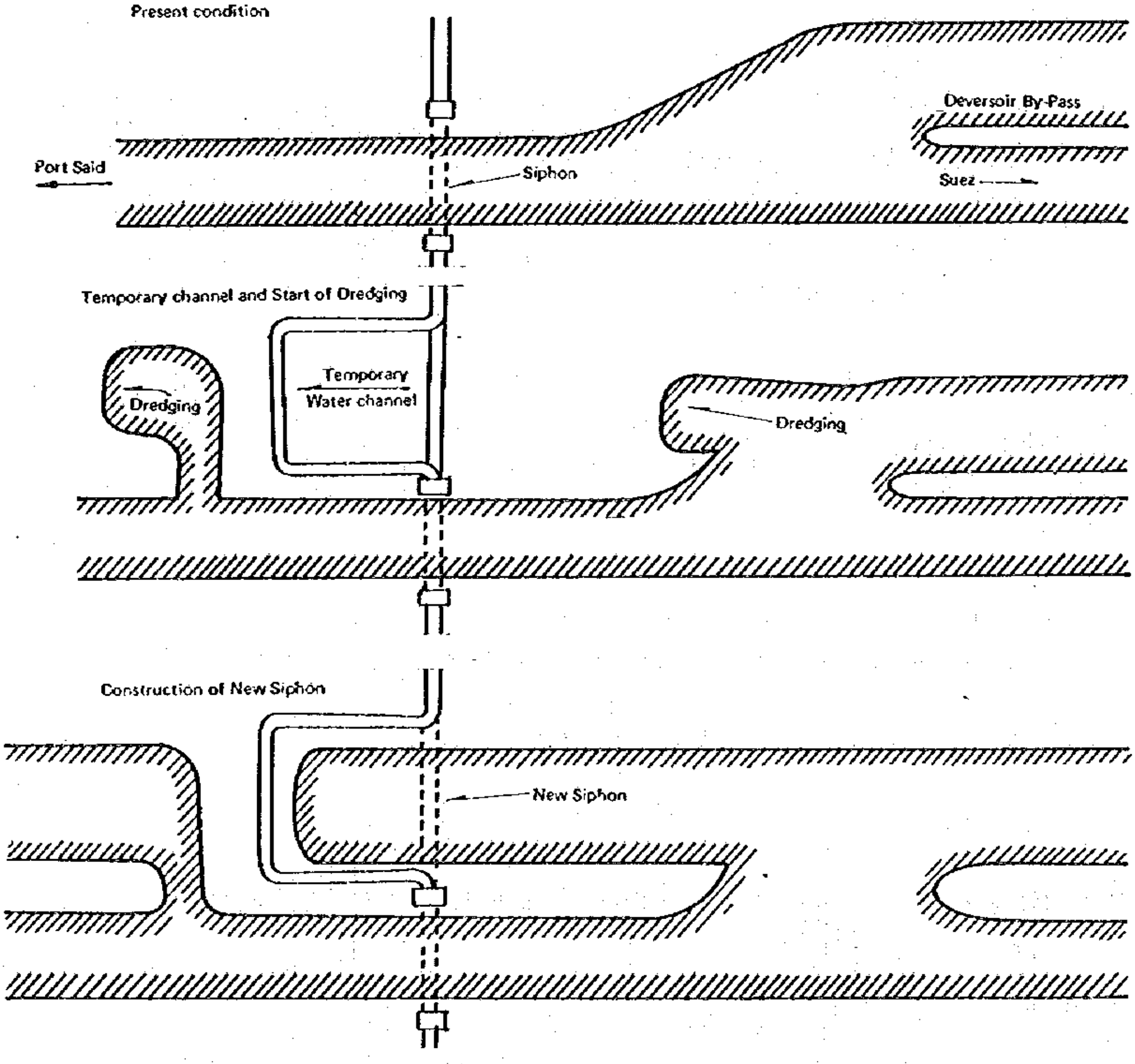


Fig. 9-2-5 Construction of New Siphon

The section of temporary channel will be dredged after the new siphon is completed.

3. Work Schedule

The work schedule will be made based on the results of Part IV and Part VII, that is, Step 1 of Phase I (Km 51 to Km 122.1) will be completed by 1984 and put into service in the first half of 1985, and Step 2 of Phase I should be completed from the latter half of 1986 to the first half of 1987, and should be opened by the beginning of 1988 at the latest. The main works of this project are dredging and the time of the start of dredging, the number and capacity of dredgers and the time of completion should be determined initially, then the work schedule for the dry excavation, bank works and other affiliated works should be determined on the basis of the progress of dredging of the main work.

To bring the dredging to the highest efficiency, dry excavation, bank works and construction of banks for the dumped spoil pool should be executed beforehand. The roads and railways should be switched to substitute lines prior to the dry excavation. The time of beginning the dredging should be determined on the basis of these prior works.

The start of construction as an element of the work schedule has been decided as follows:

It takes about two years under normal conditions from the time when the SCA decides to execute the Plan, to the time when the foreign contractors start dredging. With this process expedited, it may take 1.5 years.

For these reasons, it is assumed in making the work schedule that the local contractors can start work in the first half of 1981, the dredgers owned by SCA can start in the middle of 1981, and the foreign contractors start dredging in the end of 1981. This has been chosen as the present work schedule.

Dry excavation and bank works should start as soon as possible at the section between Km 16 and Km 32.5, and the dredging start as soon as possible thereafter. The roads and railways should be rerouted prior to the start of dry excavation at the section between Km 57 and Km 74.5, and military facilities moved from this area. Therefore, after the one year needed for preparing these works, the dry excavation and bank works will start. The dredgers will start in the later half of 1982.

The work at the section between Km 72.5 and Km 94.5 should be executed after the adjustment of the siphons of sweet water crossing the channel. A schedule should be made for the dry excavation and bank works first and then dredgers after, but the excavation shall start from the point around Km 91 in the direction of Port Said as mentioned on 2--4, and the section to Km 94.5 should be completed by dredging after completion of the siphon work. Four 8,000 PS dredgers are necessary, but one dredger will start from each side at Km 72.5 and Km 91 in the beginning, and the other two dredgers will dig soil for the expansion of width and depth of the West Channel in the section between Km 94.5 and Km 122.1. The work at the section between Km 122.1 and Km 135 will be executed by those dredgers as a Step 2, after the completion of the work in the section between Km 57.5 and Km 94.5. However, on dredging to the south side of Km 122.1 during the Step 2, 50% or fewer dredgers will be used compared with Step. 1.

The chart of this work programme is as shown in Fig. 9-3-1.

The work period shown on the chart is for real working days, and does not include the times for preparation and arrangement. In case of dredging, about one month may be necessary prior to dredging work for surveies, installation of discharging pipes, installation of submerged crossing pipeline at the section between Km 57 and Km 74.5, etc. Also, check survey and other works will be necessary after the completion of dredging works, and several months might be required after dredging before the channel is ready for navigation.

Fig. 9-3-2 is a work schedule to complete Phase I, corresponding to the High Case of demand forecast. The group of SCA dredgers will execute the work at the section between Km 32.5 and Km 53 under this programme, and the work should start earlier than in the Programme 1 or the dredging rate increased to complete the work in this section by the end of 1984. The work at the section between Km 16 and Km 32.5 will be executed by contractors, and they will work continuously in the section between Km 57.5 and Km 74.5 after the completion of the above work. In this case, about 10 MS for dry excavation should be added. The dredging work in the section between Km 122.1 and Km 135 will start in the beginning of 1982 and will be finished by the end of 1984 by dredgers equivalent to 16,000 HP. In the Programme 3, the work to Km 145 will be finished with an increase of dredgers by the end of 1984, and the complete double canal will be ready by 1986. Even in this case, the total quantity of dredgers is equivalent 164,000 HP at maximum, or 218,000 HP dredgers. The above figures are less than the number of dredgers and total power during the First Stage Project, so there are no problems for the dredging work. The dry excavation and bank work are larger than in the case of the First Stage working volume, and there is some questions of the capability of local contractors.

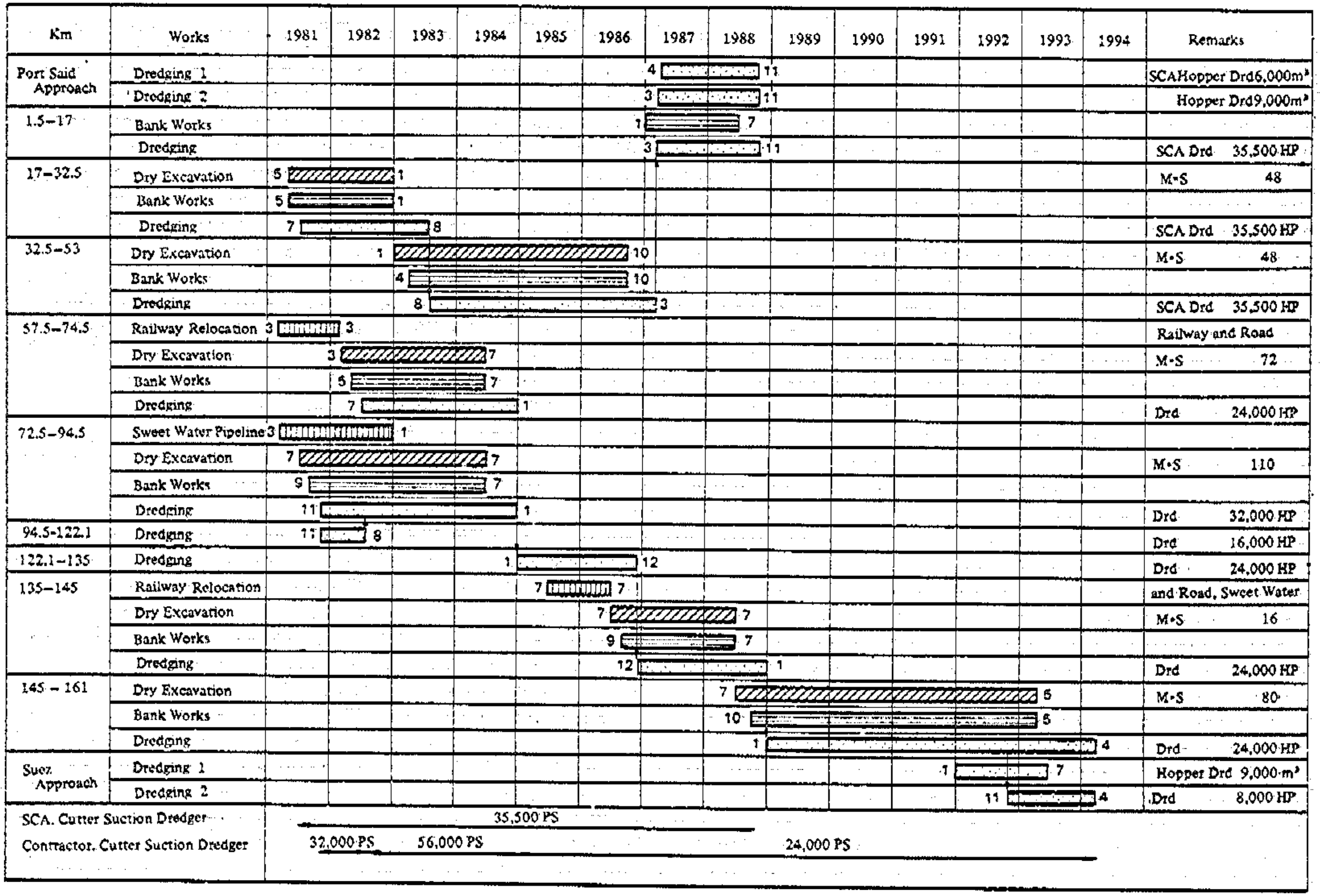


Fig. 9-3-1 Implementation Programme 1

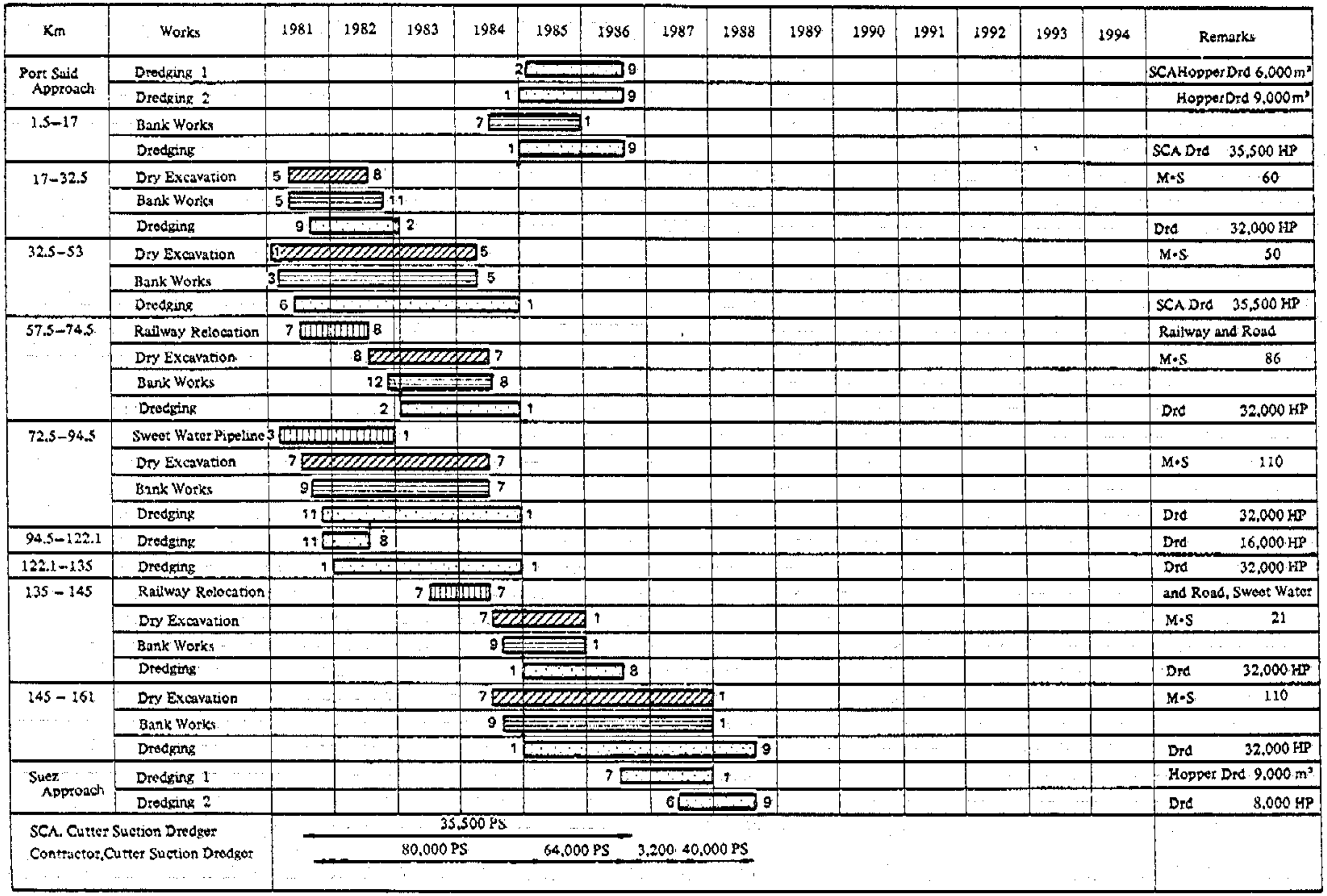


Fig. 9-3-2 Implementation Programme 2

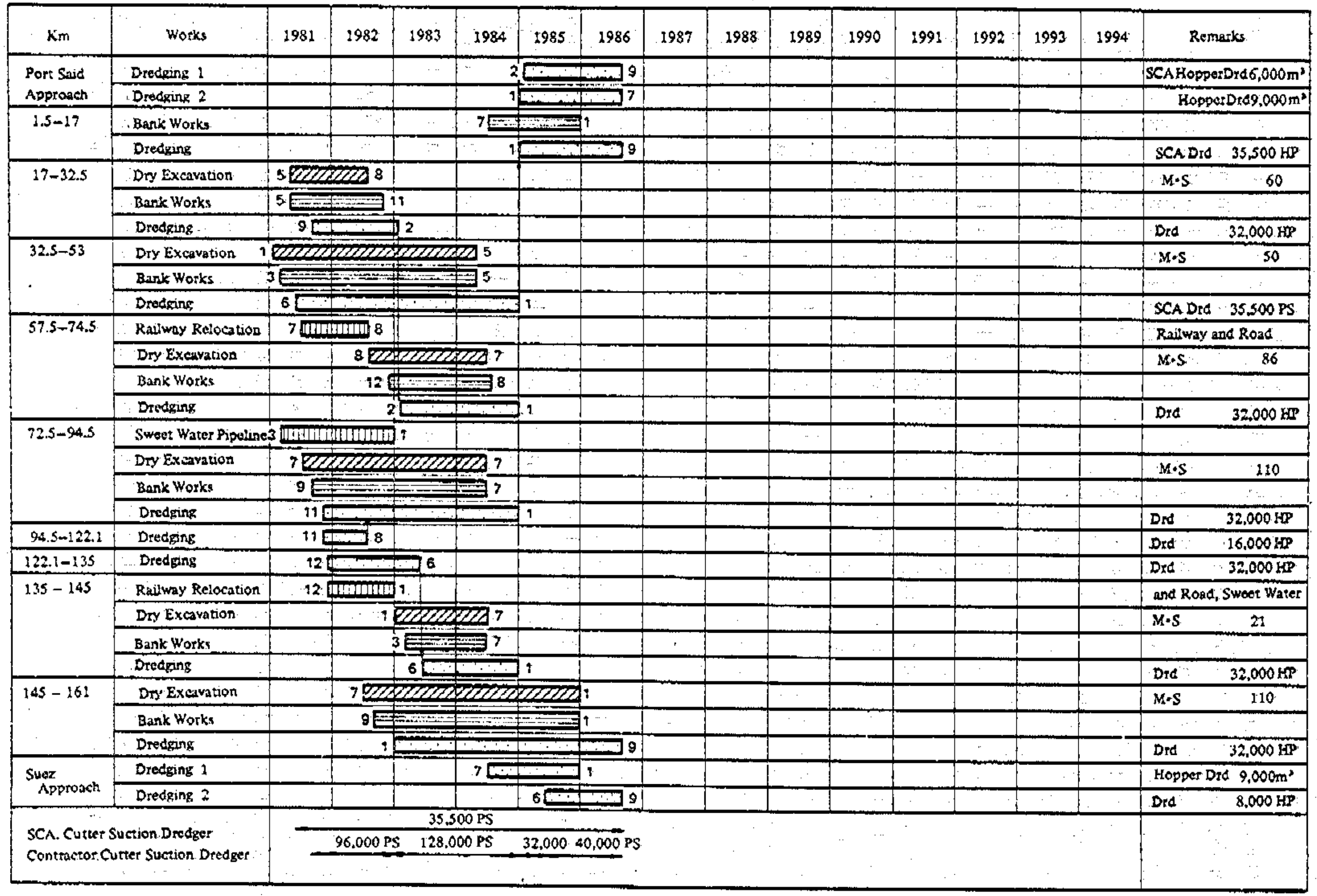


Fig. 9-3-3 Implementation Programme 3

4. Construction Cost

4-1 Unit cost

The construction cost of the Second Stage Project is estimated on prices of 1979. The unit cost of dry excavation has been chosen on the adjustment of the rise in prices by 1979, and the dumping distance. The unit cost of revetment was calculated from the total materials and volume of works in the design section. The unit cost of contract dredging is calculated from the monthly soil volume under the Second Stage Project estimated based on the actual results of the First Stage Project, and from the dredging expenses for one month. The unit cost of dredging is based on the dredging achievements under the First Stage Project up to September 1979. Therefore, the unit costs must be recalculated if the dredging efficiency thereafter has been greatly changed by encountering a hard stratum and/or the finishing work. The unit cost of dredging of the SCA fleet is calculated with the unit cost based on the actual results of the First Stage Project, taking account of price hike, and the percentage of dredging capacity for each LOT. The unit cost of dredging in the approach channel is calculated from the actual results of the First Stage Project taking account of price hike. The allotment of local and foreign currencies is based on the ratio in the First Stage Project except the contract dredging. In the contract dredging, the dredging expenses for one month is divided into local and foreign currencies, with the foreign currency calculated in Yen, under a conversion rate of ¥240 yen for $1 USD.

4-2 Construction cost

The construction cost of the Second Stage Project is as follows:

The construction cost is around LE 440 million plus US$ 500 million. The total amount in US dollars is $1,150 million. From this amount, the cost of dredging is 55%, of dry excavation is 28%, of bank works is 15% and of other works is 2%. Among the 55% for dredging, 51% is for the section between Km 1.5 and Km 161 and 4% is for the approach channels of Port Said and Suez. The exchange rate of local and foreign currencies used for the calculation is the averaged exchange rate of December 1979; 0.69LE=1US$=240 Yen.

The unit costs of the dry excavation, bank works and dredging by the SCA were divided into local and foreign currencies according to the ratio of cost shown in LE in the First Stage Project. The foreign currencies were converted to $ by the above exchange rate. The unit cost of contract dredging was estimated in LE for local portion and Yen for the foreign portion.

The following items are not included in the cost estimate:

1 Mobilization and demobilization of dredgers.

2 Unexpected cost increase in dredging due to accidents such as explosion of mines at the canal bottom.

Table 9-4-1 Cost of Second Stage Project

Km	Dry Excavation		Bank Works		Dredging		Others	Remarks
	L·C	F·C	L·C	F·C	L·C	F·C	L·C	
	10^6 LE	10^6 $	10^6 LE	10^6 $	10^6 LE	10^6 $	10^6 LE	
1.5 – 16			11.1	4.6	15.1	8.5		
16 – 32.5	12.4	1.5	11.8	5.0	21.3	12.0		
32.5 – 52	31.2	4.0	15.3	6.4	33.6	18.9		
52 – 58								
58 – 73.5	29.4	3.7	12.3	5.2	8.3	59.2	8.4	
72.5 – 94.5	57.0	7.2	15.8	6.6	11.9	84.2		
94.5 – 134.5					7.9	56.7		
134.5 – 145	5.6	.7	12.2	5.1	6.8	48.2	4.1	
145 – 161	66.8	8.4	14.2	5.9	16.0	119.8		
Port Said Approach					6.5	15.7		
Suez Approach					4.8	19.4		
Total	202.4	25.5	92.7	38.8	120.9* ** 11.3	407.5* ** 35.1	12.5	* Km 1.5 – 161 Total **Approach Channel Total
Grand Total	L·C 439.8 x 10^6 LE + F·C 506.9 x 10^6 $							≒ 1,150 x 10^6 $

The Following should be taken considered for implementing the Second Stage Project:

1. In doubling work, the debris from the Third Middle East War may be encounted. In order to guard against damage and injury from the hazards, they must be found and disposed of prior to construction. These pre-construction works should be carried out under the guidance of the SCA, and these costs included in the construction.
2. The costs of repair, replacement or compensation arising from damages due to explosions or other contact with war debris must be covered by SCA's own funds if inapplicable to insurance claims.

4-3 Financial plan classified by each year

The financial plan classified by each year in the Implementation 1,2,3 on the Figs 9-3-1,2 and 3 in the former Chapter is shown in the Tables 9-4-2, 3 and 4.

The sum in each of the Tables 9-4-2, 3 and 4 includes a contingency of 10%. There is a difference in the total cost among Schedule 1 and Schedules 2 and 3, because the work in the section between Km 16 and Km 32.5 is carried out by the SCA under Schedule 1, while it is by contractors under Schedules 2 and 3.

The amount shown in these tables is based on the prices in 1979, and does not include increases due to future inflation.

Regarding Schedule 1 and 2, the amount of funds divided into Phase I and Phase II is shown in the Table 9-4-5.

The ratio for Phase I and Phase II is 60% and 40%, respectively.

Table 9-4-2 Cost Disbursement Schedule 1

(L·C x 10^6 LE, F·C x10^6 $)

Year	Dry Excavation		Bank Works		Dredging		Other		Equipment		Total	
	L·C	F·C	L·C	F·C	L·C	F·C	L·C	F·C	L·C	F·C	L·C	F·C
1981	20.4	2.7	9.9	4.1	9.6	10.9	4.2				44.1	17.7
1982	30.3	3.8	14.0	5.8	16.3	58.7	4.2				64.8	68.3
1983	34.5	4.3	13.2	5.4	15.5	52.7					63.2	62.4
1984	34.5	4.3	13.2	5.4	15.5	52.7					63.2	62.4
1985	10.4	1.4	5.1	2.2	11.9	27.3	2.0			28.1	29.4	59.0
1986	1.9	0.2	4.0	1.7	11.9	27.3	2.1			7.5	19.9	36.7
1987	1.9	0.2	9.6	4.0	15.4	36.9					26.9	41.1
1988	13.0	1.6	12.0	5.0	15.4	36.9					40.4	43.5
1989	11.1	1.4	2.3	1.0	2.6	20.0					16.0	22.4
1990	11.1	1.4	2.3	1.0	2.6	20.0					16.0	22.4
1991	11.1	1.4	2.3	1.0	2.6	20.0					16.0	22.4
1992	11.1	1.4	2.4	1.1	4.3	26.4					17.8	28.9
1993	11.1	1.4	2.4	1.1	4.3	26.4					17.8	28.9
1994					4.3	26.4					4.3	26.4
Total	202.4	25.5	92.7	38.8	132.2	442.6	12.5			35.6	439.8	542.5

Table 9-4-3 Cost Disbursement Schedule 2

(L·C x 10^6 LE, F·C x 10^6 $)

Year	Dry Excavation		Bank Works		Dredging		Other		Equipment		Total	
	L·C	F·C	L·C	F·C	L·C	F·C	L·C	F·C	L·C	F·C	L·C	F·C
1981	28.3	3.6	13.8	5.8	12.0	32.2	4.2				58.3	41.6
1982	38.0	4.7	17.8	7.5	18.0	75.1	4.2				78.0	87.3
1983	31.9	4.0	11.9	4.9	18.3	77.1	2.0			28.1	64.1	114.1
1984	51.3	6.5	27.0	11.3	18.3	77.1	2.1			7.5	98.7	102.4
1985	19.5	2.5	15.2	6.3	18.7	66.5					53.4	75.3
1986	16.7	2.1	3.5	1.5	20.4	72.9					40.6	76.5
1987	16.7	2.1	3.5	1.5	5.6	36.4					25.8	40.0
1988					5.6	36.4					5.6	36.4
Total	202.4	25.5	92.7	38.8	116.9	473.7	12.5			35.6	424.5	573.6

Table 9-4-4 Cost Disbursement Schedule 3

(L·C x 10^6 LE, F·C x 10^6 $)

Year	Dry Excavation		Bank Works		Dredging		Other		Equipment		Total	
	L·C	F·C	L·C	F·C	L·C	F·C	L·C	F·C	L·C	F·C	L·C	F·C
1981	28.3	3.6	13.8	5.8	12.0	32.2	4.2				58.3	41.6
1982	54.8	6.8	21.3	8.9	19.1	82.6	8.3				103.5	98.3
1983	51.3	6.5	21.5	9.0	26.7	138.6				28.1	99.5	182.2
1984	51.3	6.5	27.0	11.3	25.1	122.7				7.5	103.4	148.0
1985	16.7	2.1	9.1	3.8	17.0	48.8					42.8	54.7
1986					17.0	48.0					17.0	48.0
Total	202.4	25.5	92.7	38.8	116.9	473.7	12.5			35.6	424.5	573.6

Table 9-4-5 Cost of Phase I and Phase II

(L·C x 10^6 LE, F·C x 10^6 $)

Year	Dry Excavation		Bank Works		Dredging		Other		Equipment		Total	
	L·C	F·C	L·C	F·C	L·C	F·C	L·C	F·C	L·C	F·C	L·C	F·C
Phase I	130.0	16.4	55.2	23.2	83.0	231.0	8.4			35.6	276.6	306.2
					67.7*	262.1*					261.3*	337.3*
Step 1	86.4	10.9	28.1	11.8	20.2	143.4	8.4				143.1	166.1
Step 2	43.6	5.5	27.2	11.4	62.8	87.6				35.6	133.6	140.1
					47.5*	118.7*					118.2*	171.2*
Phase II	72.4	9.1	37.5	15.6	49.2	211.6	4.1				163.2	236.3

* Schedule 2, 3

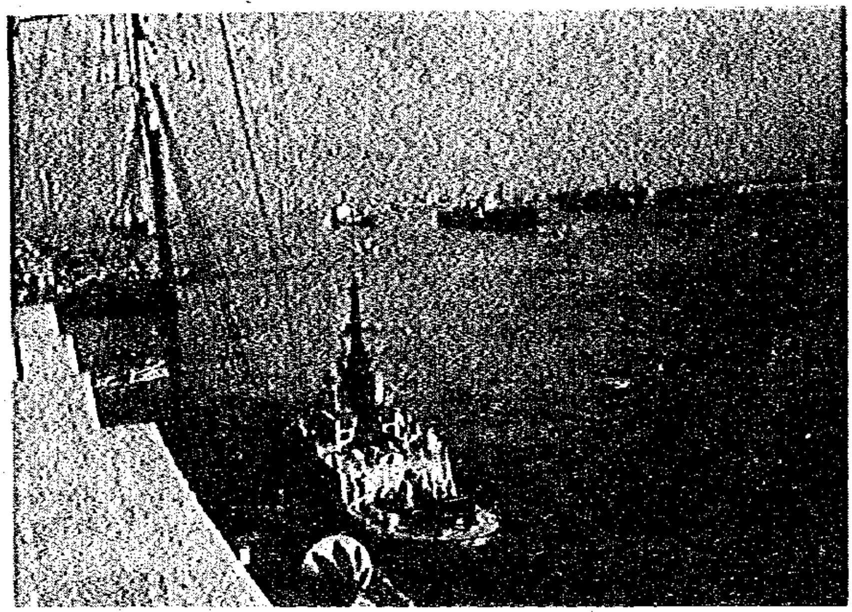
5. Construction Management System

To put the work experiences of the First Stage Project to practical use in the Second Stage, the weak points should be improved during the Second Stage after consideration of the First Construction Project problems. First of all, the management and control for each of mutually related works of dry excavation, bank works and dredging should be revised. Under the First Stage Project, situations when the dredgers were delayed occured due to delays in dry excavation, embanking for spoil and revetment work, with the result a delay in the time of completion. If the reasons for the rest of dredgers were analyzed, there were many cases caused by unexpected obstacles, summing almost double of the rest time for waiting the convoy. The obstacles supposed to be removed during the removal work of revetment and dry excavation were left in place, furthermore interruptions in dredging occured from obstacles thrown into the water. The work process, the field management and inspection should be strict, and the extension of the construction period due to these troubles should be eliminated.

Thorough planning for the safety of works is very desirable. Troubles due to collisions of ships transiting and sinking and damage dredgers due to the explosion occured several times in the First Stage Project. Even if there are fewer cases of ships transiting in the channel where the dredgers are working, and collision and damage dangers are decreased under the Second Stage Plan, both of dredgers and ships should maintain regulations and take safety measures. Also, the investigation and management of the explosives were given attention in the First Stage Project but the trouble due to explosion occured, therefore, complete safety plans must be made.

Reliability in construction works is required. The revetment under the First Stage Project were found broken in several locations after the completion. While the reasons for the failure are not complately clear, the construction may not have been surely executed, as indicated from the shapes of collapse and the conditions of distribution of the damaged revetment. To execute the work surely under the design, the inspection of the works should be performed and strict conformance to design standards required.

Finally, the submerged pipeline crossing the channel for discharging spoil dredged in the west channel to Sinai Penninsula side will be installed. If the soil leaks from the submerged pipeline the soil will accumulate in the bottom of the channel and there is a possibility transiting vessels running aground. The maintenance and inspection of the submerged pipeline should be regularly performed.



X. Administration and Operation

PART X. ADMINISTRATION AND OPERATION

1. Administration and Operation

No particular problem exists in the control and management of the Canal after the completion of the Second Stage Development Project, so long as there is no qualitative change in the utilization of the Canal and measures are taken to strengthen the control and management system. In this part, from the experience of navigation control in Japan, the safe management of the Canal traffic after the First Stage Development Project is discussed.

1-1 Suez Canal Vessel Traffic Management System (SCVTMS)

Suez Canal Authority has begun installation of SCVTMS, an epoch-making wide navigation control system, which is scheduled to be implemented at the end of 1980. In the course of designing this system, the use of hardware with highly advanced electronics and software based not only on the navigation control but on the management plan for the Canal has been studied. The second phase survey, conducted in December 1979, revealed only the outline of the plan; detailed investigation and collection of reference data could not be carried out.

In view of these facts, a traffic management system will be described, based on the experience in constructing and operating the navigation control system of Tokyo Bay, in which vessel traffic controls were computerized for the first time in the world.

No matter how strictly navigation is controlled, it is impossible to prevent all the accidents. The more the management attempts to minimize the probability of accidents, the more expense is needed. Naturally, the question on the effect to cost and benefit should be considered. When the control system is designed, the scale of possible incidents should be taken into consideration and the target for preventing incidents should be set at the level of a serious incident case. With the completion of the First Stage Development Project, SCVTMS timely set a target for the safe navigation of VLCC, and is expected to largely contribute to the safe navigation of VLCC. Since a marine accident of VLCC is highly probable to become a very serious accident which would temporarily result in the Canal closure, the establishment of SCVTMS will guarantee the safe navigation of the vessels and increase reliability on the Canal, and eventually greatly benefit in the operation of the Canal.

1-2 Control and Operation by SCVTMS

In view of the actual situations of navigation and marine accidents in the Canal, the following controls over the transiting vessels can be considered. The control work consists mainly of controlling and supplying various information. The contents of the work and the process are as follows:

Items		Contents	Source and Related matters
1. Collection and arrangement of advance notice.	a)	Reception of advance notices from the vessels at Port Said (Suez), ETA (Estimated Time of Arrival), etc.	Data processing, communications, compilation of a Nav. Plan,
1) Information on vessel traffic.	b)	Collation from the harbor control room on the arrival and departure of vessels.	Communications, Marine
2) Ports and Canal information	a)	Present situation of the port of Port Said (Suez) and the Canal	Radar, TV, Harbor control room, Marine Center
	b)	Dredging operation plan	Dredgers, construction dept.
	c)	Plan of temporary work and floating bridges erection	Signal stations, Military.
	d)	Forecast of meteorological and sea condition	Weather station, Harbor control room, signal stations
2. Preparation of a control plan & advance instruction, etc.	a)	Adjustment of vessel time schedules for entering and departing the port, as well as for entering into the Canal. Adjustment of transit time for each vessel.	Harbor control room, Marine Center, data processing, presentation of navigation schedule.
1) Control plan			
	b)	Adjustment among construction works, floating bridge erection and convoys in the Canal.	Presentation to the related dept., signal stations, Nav. plan: Data processing.
	c)	Setting up the crossing time for convoys.	– ditto –
	d)	Maintenance of proper time interval between vessels (the towing object, low speed vessels and the vessel with engine trouble)	Harbor control room, Marine Center, signal stations.

Items		Contents	Source and Related matters
2) Advance instruction	a)	Navigation time table, navigation order in the convoy, arrangement of escort tugs, and mooring boats, reception of wireless, contact with control officers during transit through the Canal.	Marine Center, Harbor Control room, communication.
	b)	Changes in time schedule for entering and leaving of the port, as well as for entering into the Canal	Nav. plan Harbor Control room, Marine Center, signal stations.
3) Revision of the control plan.	a)	As changes are made in the navigation plan, the control plan should be timely revised and related instruction should be issued.	Harbor control room, Marine Center, signal stations.
3. Collection, arrangement of information on the entrance dates of vessels into the Canal, and the observation by TV monitors	a)	Discriminating vessels by CORT (Carry on Receiver Transmitter) and providing them with ID tag. (Port control officer)	Radar, Display, Fix display.
	b)	Present and forecasted situation of vessel traffic.	
1) Information on the vessel traffic.			
2) Canal-route information	a)	Progress of construction and other works	Marine Center
	b)	Present situation of navigation aids.	
	c)	Sea Condition and meteorological forecast.	Partial weather station
	d)	Progress of temporary work and floating bridge erection.	
4. Supply of information		The transit vessels will be provided by wireless or VHF with the following information which is collected and arranged.	

Items	Contents	Source and Related matters
	a) Information on convoys passing major points (The position and speed of the first and the last vessels)	Fixed display, signal stations, communication.
	b) Progress of construction works	
	c) Revision, abolishment and accidents concerning navigation aids.	
	d) Sea condition and meteorological forecast (warnings & notices)	Partial weather station.
	e) Reports on marine accidents	
	f) Situation of temporary work and floating bridge erection in the Canal.	
	g) Ships at anchor within the Canal. (Including bypass)	
5. Observation of Display (Presentation of site situation)	Judging from the warnings issued by the early warning system, and the traffic situation within the Canal, the following warnings should be delivered to the vessels.	Communication, warnings
	a) Warnings against speeding	
	b) Warnings against deviation of course (abnormal course)	
	c) Warnings against improper time interval between vessels (much closer or longer distance than instructed)	
	d) Warnings against low speed	
	e) Emergency stop, refuge and mooring orders in the case of marine accidents	Issuing orders simultaneously by VHF
	f) Leading instructions in the case of poor Visibility	Marine Center Signal Station

1-3 Staff for SCVTMS

(1) Control officer: The latest electronics technology is adopted to the new control system. In order to maintain and manage the system, human factor is very important. Whether the system will succeed or not largely depends on the human factor, that is, the quality of the control officers. From examples of Traffic Advisory Service Center in Tokyo Bay and present systems in Europe and the USA, it is apparent that adequate research on human factors have not yet been conducted. A control officer, however, is required to have intelligence to communicate on even terms with pilots, and professional knowledge in the fields of sailing, maneuvering, marine transportation, maritime laws and regulations, communications, disaster prevention, rescue operations, etc. Chief control officers, therefore, are selected from among pilots, officers of navy or merchant ships, and those who have experience as captains. Other officers should also be selected from navigation department officers who have experience in navigation business, radio operators, or electronics engineers. They should be provided with educationd training in the above mentioned fields. Highly developed observation skill is particularly required to the control officers. The control system will be operated round-the-clock using 3 or 4 shifts. A proper time schedule for one officer to be observing the display is two hours, with a 30 minutes rest period following; from our experience two hours are the limit for every one to maintaining high awareness in tense situations.

(2) Maintenance officers: The control system is operated according to real time. Confusion caused by trouble or deterioration of functions at any part of the system will lead to a chaos in the Canal traffic, which may invite a serious accident. This system is an extremely complicated and large-scale one with full diversity, including even human factors. It requires a management system to observe functions and operations of various equipment, to maintain and adjust them, and to be able to promptly rehabilitate operation in the wake of an accident or a trouble. Single unit equipment, such as a radar or a loran, must have very high reliability. The automatic processing system which locates and traces objects caught by the radar, determines the velocity, calculates its collision probability, predicts its future location and so forth, has nearly come to its completion, except for some defects rising from the characteristics of radars. The system is comprised of a great number of computers and subsidiary equipment. The number of parts is so large that maintenance and management are extremely important. However, unexpected accidents will frequently happen with radar, loran, communication equipment, computer and subsidiary equipment which utilizes highly advanced electronics technology, especially during the installation of equipment and the trial period. In the second year of operation, the system will be stable with few problems, but in the third or fourth year, frequently used parts will begin to give trouble. In order to maintain and manage the system, specialists in hardware and software are necessary. Since this application of equipment is unique, specialists dispatched from the manufacturer must participate in the management team of the SCA for several years. It is recommended that SCA prepare a program to train maintenance officers for 3 to 5 years. The officers should be selected from SCA staff members under thirty years of age and have knowledge of electronics. They will participate in the maintenance work from the time the equipment is installed. They must learn techniques through on-the-job training and studies provided by the engineers form the manufacturer. Moreover, SCA should regularly employ

college graduates who majored in electronics technology and train them to become senior engineers.

1-4 Radar and data processing

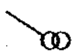
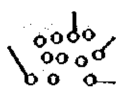
1-4-1 False images of a radar

One of the problems of the data processing of images caught by a harbor radar is a false image. This problem should be corrected before operation. The causes are 1) multi-reflection against the buildings surrounding the radar station and their subsidiaries, 2) multi-reflections against vessels, 3) Reflected waves against breakwaters and other things, 4) rain, thick rain clouds, dense fog, 5) side lobes. If the echoes of these articles are processed by computers and shown on the TV monitors, it is very difficult to discriminate vessels and images, and virtual collisions between a false image and a vessel or virtual accident to strand will be predicted on the TV monitors. Such false images make observation by control officers very difficult.

(1) The shapes of virtual images:

The virtual images shown on TV monitors are as follows:

Description on false images

False image on TV	Description of false images	Degrees of difficulty in discrimination
	High speed, course changes, disappears in a short period of time.	Very easy
	The same as the image of vessels.	Difficult
	The same image as that of a vessel coming towards another vessel.	Rather difficult
	The same image as that of a cruising vessel coming towards another vessel at anchor	– ditto –
	The same image as two vessels anchoring at points very close to each other.	– ditto –
	The same image as that of a vessel which is about to cast anchor or a vessel which has just started cruising.	– ditto –
	The same image as that of fishing boats gathering in a small area.	Easy

(2) Discriminating methods of false images:

a) As the false images are created by multi-reflections or side lobes, the echoes are vague and unstable.
b) The false images caused by buildings will appear in specific areas.
c) False images can be discriminated by shape, density and stability of the PPI (Plane Position Indicator) images.
d) Erasing methods of the false images: The images which remain for certain times of rador sweep will be processed and indicated. In this case, the images of small vessels may also be erased and, therefore, careful adjustment is needed. The creation of false images may be due to the radar site and the height of the antenna, and to erase the false images completely is not possible. However, it is possible to make up for it to a certain extent by simultaneously observing through PPI.

1-4-2 Disappearance of the image

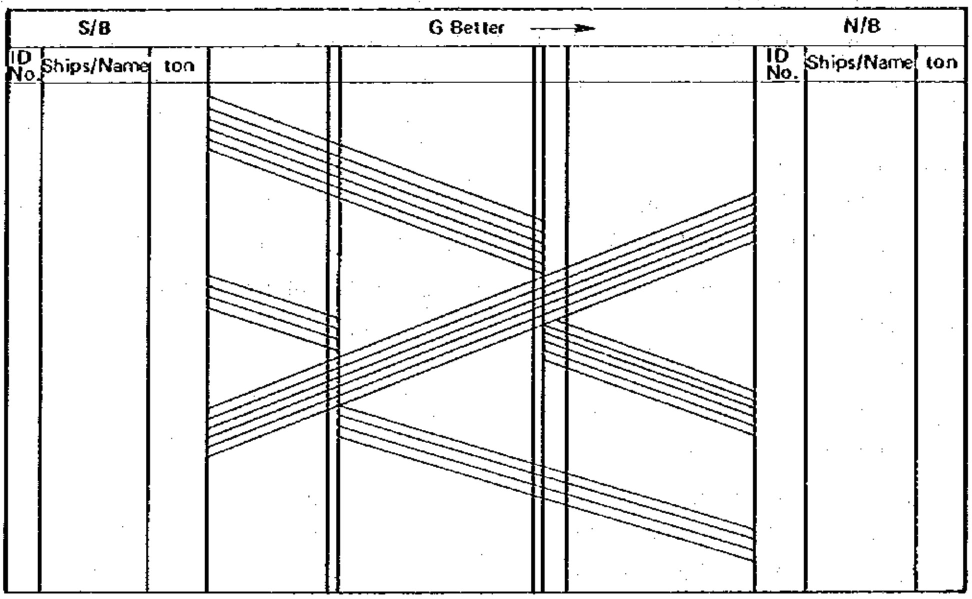
In the fields of marine traffic, vessels are classified into 4 types, mammoth, large, medium, and small. When the traffic is controlled, the question of how to handle the small vessels should be studied from various aspects such as laws and regulations, the situation of the traffic in the Canal, as well as the capacity of CPU (Central Processing Unit).

(1) Ground reflection
It is very difficult to hold down ground reflection within and outside the port. It is also very difficult to detect, with high accuracy, small objects with narrow effective areas of refleciton, such as bouys and small boats. Holding down the clutter is a serious problem which will influence on the reliability of the control system and special attention must be paid to it.
In order to hold down ground reflection, the occurences under certain sweep intervals are eliminated from the process.
(2) Disappearance caused by obstacles
An image of a vessel may disappear when it passes behind a large vessel or a building. In this case, the image should be pursued and represented on TV monitor for a short period of time using the information of its course and speed before the disappearance.
(3) Disappearance caused by alter of course
Disappearance is caused by turning of a vessel when it changes direction, causing the reflecting area change, and so the center of the image moves. This results in the appearance of the speed and course of the vessel to change constantly against the actual motion of the vessel. In this case, the moves of the image are generally indicated after being averaged on the software, mixed with the past data. However, when the vessel makes a big turn, the radar cannot pursue and detect the object, because of the past data, and eventually the image disappears. For this reason, programs on the vessel's straight advance and its change of direction should be prepared, so that the image will correspond to the actual move of the vessel and a big time-lag can be prevented. This is closely related with the efficiency of the automatic warning system against collisions.
(4) Interference by ground waves and ground reflection waves
Sometimes, images disappear when the sensitivity of a radar deteriorates due to the

interference effect of direct waves and ground reflection waves. This phenomenon occurs in the areas some distance away from the radar station. If the radar station is constructed as one of the radar chains, the circuits for signals, for observing and for remotely controlling the radar operation are indispensable. As micro waves are used for these circuits, the location of the main station and the unmanned stations or climate may sometimes cause deterioration of radar sensitivity because of interference effect or noises by direct waves and ground reflection which results in a break of the circuits. Special efforts are required to avoid the interference areas, by changing the direction of the antenna and so forth.

1-4-3 Equipments to be installed in the control room

An indication board to show the progress of each convoy is essential in the control room. On the board, a sign of southbound and northbound, an identification number, the name of the vessel, its tonnage and loading of dangerous commodities are indicated.



The indication baord is designed to adjust vessels not to cross each other on the waters except for crossing zones. For that purpose, entrance schedules of vessels coming in from both southern and northern entrances must be adjusted. The speed of the vessels should also be adjusted. These calculations will be done by electronic computers and the result will be indicated on the board. Names of the vessels, their ID No. and their tonnage, etc. will be obtained from the Navigation plan and the data on the vessels, and will be listed according to the navigation order in the convoys of southbound and northbound.

2. Operation and Facilities

2-1 Present situation

2-1-1 Tug-boats and fire fighting facilities

With the completion of the First Stage Development Project, large tankers are expected to transit the Canal. Marine accidents of large tankers are possible to cause serious accidents which will result in the Canal clousure. SCA, therefore, has increased the number of salvage and escort tug-boats and strengthend their maintenance since 1978. It has provided these boats with fire fighting equipment. At the moment, SCA's tug-boats are as follows:

Rescue and escort tug-boats 19
Harbour tugs 13
Large pilot boats for outside ports 2
The items are indicated in Tables 10-2-1, 10-2-2 and 10-2-3.

Table 10-2-1 Salvage Tugs

No.	Name		G/T	H.P.	Speed	Year Built
1	Shahm	No. 87	1,390T	4 x 1,600	24 km/h	1960
2	Mared	No. 99	1,390T	4 x 1,600	24 km/h	1960
3	Antar	No. 90	1,390T	2 x 2,500	28 km/h	1954
4	Moawen/1	No. 171	279. 44T	2 x 1,600	13.84 kt.	1975
5	Moawen/2	No. 172	282. 41T	2 x 1,600	14.00 kt.	1975
6	Moawen/3	No. 173	282. 59T	2 x 1,600	13.79 kt	1975
7	Moawen/4	No. 174	199. 70T	2 x 1,300	13.72 kt.	1975
8	Fahd	No. 134	249	2 x 1,700	12.00 kt.	1976
9	Nimr	No. 133	249	2 x 1,700	12.00 kt.	1976
10	H. Bahgât	No. 264	362	2 x 1,850	13.80 kt.	1978
11	F. Bakr	No. 265	362	2 x 1,850	12.75 kt.	1978
12	Baher/2	No. 266	362	2 x 1,850	13.00 kt.	1978
13	Barei/2	No. 267	362	2 x 1,850	13.20 kt.	1978
14	Bassel/2	No. 268	362	2 x 1,850	12.90 kt.	1978
15	Batal/2	No. 269	362	2 x 1,850	12.90 kt.	1978
16	Salam/1	No. 281	387	2 x 2,000	12.00 kt.	1978
17	Salam/2	No. 282	387	2 x 2,000	12.00 kt.	1978
18	Salam/3	No. 283		2 x 2,000	12.00 kt.	1978
19	Salam/4	No. 284		2 x 2,000	12.00 kt.	1978

Table 10-2-2 Harbour Tugs

No.	Name		G/T	H.P.	Speed	Year Built
1	Kirsh	No. 103	280	1,600	23.1 km/h	1958
2	Chedid	No. 109	240	1,600	23.1 km/h	
3	Morgan	No. 110	240	1,600	23.1 km/h	1958
4	Shabar	No. 111	240	1,600	23.1 km/h	1958
5	Boury	No. 117	153	1,640	12.77 km/h	
6	Wakar	No. 118	153	1,640	12.77 km/h	1962
7	Denis	No. 120	153	1,640	12.77 kt.	1963
8	Kader	No. 129		2 x 800	11.0 kt.	
9	Bateh	No. 128	160	2 x 800	21.9 kt.	1975
10	Hoût	No. 92	400	960	21.9 kt.	1957
11	Ras El Esch	No. 141	240	1,600	12.5 kt.	
12	Shedwan	No. 143	260	1,600	12.5 kt.	
13	Bayad	No. 145	240	1,600	12.5 kt.	

Table 10-2-3 Pilot Boats

No.	Name		G/T	H.P.	Speed	Year Built
1	Morshed	No. 101	760	2 x 1,400	27 km/h	1950
2	Mounir	No. 105	1,054	2 x 1,640	15.89 kt.	1962

2-1-2 Equipments and materials for remvoing oil:

So far, there has been no accidents of large-scale oil leakage in the Canal. SCA's present equipment and materials are as follows:

a) Oil removal unit ..... Rheinwerft (West Germany) ... 1 unit, capacity ..... 10 m/h, Port Said Port.
b) Oil dispersant 100 tons, Rochen Dispergent, Port Said Port, stored at Port Twefic and other signal stations.
c) Oil booms: Light type ... 600 m. Made by Bridgestone (Japan) Steel pipe ... 200 m.

2-1-3 Disaster prevention drill

SCA has not conducted organized disaster prevention drills, but crew memebrs of tug-boats participate in the fire fighting training course provided by Port Said Municipal Fire Fighting Agency.

2-1-4 Navigation Aids

Navigation aids, such as light-buoys, and light beacons are placed at regular intervals of less than 3 kilometers on both sides of the water channel to meet the geography of the area. Besides, leading lights, tidal current buoys, buoys to indicate mooring restrictions and rock areas, etc. have been installed. The number of navigation aids is adequate.

2-2 Operation after the First Stage Development Project

2-2-1 Improvement of facilities

(1) Fire fighting equipment on tug-boats

SCA has an intention to increase the number of tug-boats and to improve their equipment. It plans to provide tug-boats with fire fighting equipment. The number of the tug-boats which are required to meet the demands of large tankers to transit the Canal is indicated in Part VII, 5-3-1. In the actual operation, adjustment of the number of tug-boats should be made by the demand of the number of transit vessels.

According to the standard of Maritime Safety Agency in Japan, a tanker and escort tug-boats must have a fire extinguishing capacity of the following level: Supposing the maximum total surface area of two adjoining side tanks is Am^2, a tankers and escort tug-boats is required to have the following capacity;

foam sprays capacity 12A ℓ/min .... (3% foam/water mix)
foam undiluted solution storage capacity 9Aℓ

It is desirable that the total capacity of fire extinguisher and materials of tug-boats which attends a tanker are the same or better level of the standard.

(2) Materials and equipments for removing oil

In the Canal, one-way traffic is imposed on tankers, and there is low probability of their collision. The probability of their running ashore, or getting on banks, however, is high. The removing operation of oil in the wake of oil leakage accident is rather easy in the Canal as compared with that at sea, becuase winds, tides and currents seldom affect the channel. Moreover, the channels are narrow and operations from the banks are also possible. The present materials and equipments, however, are not sufficient for accidents in which the bottom of a large tanker is damaged and oil leaks. In the oil removal operation, collection of oil should be considered as main work to avoid polluting the surrounding environment. Spilled oil is to be enclosed by oil boom to prevent its spreading. Then, the oil in the boom will be collected by skimmer boats or oil removal units, and gathered in temporary tanks on the gorund. The thin spilled oil will be absorbed by oil absorbent material. The rest of the spilled oil should be completely removed by oil separating agents.

(3) Navigation aids

(a) On both sides of the Port Said By-pass light buoys or light beacons should be placed at regular intervals of one and a half kilometers. Channel buoys (unlighted) to indicate the passable width should also be placed at the same interval.

(b) At the entrance of the approach channel of the by-pass, a large light buoy equipped with meteorological observation apparatus should be placed at the intervals of one and a half kilometers on both sides of the channel. Other necessary navigation aids should also be placed.

2-2-2 Staffing

The organization after the completion of the First STage Development Project will be the same as the present one excpet for that of SCVTMS. The increase of staff members required for SCVTMS is as follows:

	(Control officer)	(Maintenance)
Central control room	(* Note)	–
Harbor control room (Port Said)	(* Note)	8
(Port Tewfik)	(* Note)	8
Loran C station		20 – 25
Computer Center		20 – 24
Communication network		6 – 8
Signal station (Port Said By-pass)	10	–
Total	10	62 – 73

*Note: Supplementation by transfer of the present manpower.

3. Tasks for Safety Control

3-1 Installation of SCVTMS

Compared with the old system under which the control officers managed traffic by receiving information from VHF and signal stations, the new system has various advantages. Under the new system, all the information on the vessel's traffic is centralized in the central control room. Control officers will closely watch the traffic with their own eyes, and are able to recognize the danger collisions and deviations from cruising courses through the automatic detector. The system is expected to show remarkable efficiency in safe navigation of the vessels (both at normal and emergency times) and reduction of loss time in transiting of the Canal. At the time of introducing the new system, however, the following problems should be solved.

(1) Joint use of signal stations

It is unavoidable to cause changes in the function of signal stations in the course of switching over to the new system. The signal stations should be maintained and operated just as before as facilities to sufficiently secure safe traffic, until the efficiency of the new system is confirmed and no troubles are found about its maintenance, management, etc. In view of this fact, the facilities should be operated as they are for several years, and later they are desirable to be operated as depots for fire fighting and Anti-pollution equipment and material.

(2) Training of control and maintenance officers

Refer to 1-3) Staff for SCVTMS.

(3) Compilation of a manual or control officers

A manual which regulates control plans, forming of convoys, controlling intervals, advance instructions, standards of traffic suspension, content of information and warings, standards and occasion of issuance of information and warnings, measures to be taken at the time of emergencies, responsibility of control officers, terms, adjustment of contact with related departments and stations, and communications and others, should be compiled. By unifying these works, trustful relations should be established between those who control and those who are controlled. At the same time, a manual for maintenance and adjustment should be made.

(4) Adoption of a system to inform location

If CORT (Carry on Receiver Transmitter) is not loaded on a vessel outside the port, it is necessary to set up a location information line at a point some ten kilometers from the radar station, and when a vessel reaches the line, its crew must report the control officers the vessel name and the passing time by VHF. The control officer will discriminate the vessel on the radar scope and give it a specific ID No. They must control traffic inside the harbor, including anchorage area for waiting.

(5) Distribution of pamphlets

In order to make efficient use of this large-scale, complicated SCVTMS, sufficient understanding and cooperation of the users (captains) are required. For this purpose, a pamphlet which briefly describes the function of the system, the equipment involved, procedures and other matters to be obeyed, and responsibility of control officers, etc. should be compiled and distributed to users of the Canal.

3-2 Emergency stop of VLCC in the Canal

It is necessary to make an emergency stop when a vessel or that which is cruising ahead of it has some trouble, or under the conditions of strong winds or poor visibility. The width of the passable water channel of the Canal is extremely narrow for VLCC.

For a large tanker, it is impossible to make a stop at a full stern without running a ground. The tanker, therefore, should be escorted by a tug-boat, and by controlling the bow, the brake must be applied so as to make a safe stop at the central part of the channel. As vessels must be stopped within the regular intervals of ships, the technique used by the pilots' maneuvering vessels, and operating methods of tug-boats, are important matters. Pilots and crew members of tug-boats must be experts at operating methods of any kind of tug-boats, so that they can take a swift action at the time of emergency. They must train in the emergency stopping techniques using escort tug-boats when they anchor at Great Bitter Lake. Moreover, technical studies should also be made on the conditions for traffic suspension of VLCC in the Canal, in order to secure safe traffic.

3-3 Promotion of measures to prevent large tanker accidents

As was mentioned before, the measures set up by SCA against the accidents of large tankers are not always sufficient. SCA, therefore, must establish a disaster prevention plan without delay, by assuming the outbreak of a tanker fire and oil leakage. (Refer to the attached hereto 'Danger circle area of tanker fire') The fire prevention plan must include, a) Counter measures against fire and oil leakage. b) Transactions of accidents (Guide of accident transactions, rescue operation) c) Transaction set-up. d) Arrangement of materials and equipment. f) Disaster prevention set-up d) Arrangement of materials and equipment. f) Disaster prevention drill of staff members. Fire fighting drills are particularly important in the sence that it will improve swift action during times of actual emergencies. As for the transaction set-up, the system of cooperation and assistance among the military divisions in charge of the protection of the Canal, police, fire stations, and most importantly the the departments within SCA must be established in advance. Swift and systematic mobilization of facilities, materials, and equipment is also very important. In order to minimize damage and cope with the accident swiftly, SCA must make close ties with private sectors.

As the time passes the spilled oil at sea are spread by wind and tide, causing wider pollution. Eventually, the area which needs an oil removal operation will expand. The efficiency of the operation will greatly vary with the thickness and the nature of the spilled oil change by water content. Thus, it is necessary to remove the oil as promptly as possible.

In Japan, all the tug-boats which escort a large tanker carry such removing equipment and materials as an oil boom, oil absorbent material and oil dispersant, in order to cope with unexpected accidents. At the moment, the tug-boats which belong to SCA do not carry this equipment or materials.

It may be necessary to study the loading of this equipment and material on salvage and escort tug-boats. These should be stored in many places, not only at Port Said and Suez, but at various locations along the Canal. The signal stations can serve well as depots. Tankers of more than 20,000 DWT in ballast are regulated to be equipped with inert gas system in thier cargo hold by the 1978 protocol, which concerns the revision of the SOLAS treaty. SCA can make the most of this system, to improve safe navigation in the Canal by making on-board checks.

(Reference) Danger circle area at the fire accidents by tankers

If a large tanker causes a large scale fire accident by spilling a large amount of crude oil, the oil will spread in all direcitons. In this case, a combustible gas hangs over the sea and is likely to cause sea surface fire. The radiant heat coming from the fire is dangerous to neighboring facilities and people. When the oil spreads over the sea, the combustible gas having a danger of combustion remains only for 50 minutes at most. Professor Motoyashi gives the following formula on the dispersing radius for spilled oil at sea and also estimates danger circle against the above dispersing circle as follows:

$$R(t) = 8\sqrt{\frac{16 \cdot g \cdot V^3}{C^2 \cdot \pi^3 \cdot \mu} \cdot t + Ro^8}$$

R(t) (meter): Dispersing radius after some lapse of time
t (second): Lapse of time
Ro (meter): The first flow radius of oil
μ (square meter per second): Kinematic viscosity coefficient of crude oil
C: Coefficient (about 0.1)
V (cubic meter): (Ps-Po) Vo
Vo (cubic meter): Total amount of oil
Ps: Specific gravity of sea water
Po: Specific gravity of oil

The size of danger circles:

(Marginal condition)	(Radius of danger circle area)
Circle of catching fire (Circle of 1/2 LEL)	2R
Marginal circle of poisoning (Circle of 1/2 LEL)	2R
Marginal circle of catching fire by radiant heat	1.25R
Marginal circle of human burns	2R
Marginal circle to avoid injury	3R

However, R is the radius of oil spreading on the sea after 60 minutes. LEL is the abbreviation of lower explosive limit. The danger circles calculated by taking the quantities of the spilled oil and the wind velocity into consideration are indicated below:

Danger circles (Radius)

Quantities of the spilled oil (m^3)	Wind velocity (m/sec)	Radius of the oil spill (m)	Danger of catching fire (m in circle)	Danger of poisoning (m in circle)	Danger circle by radiant heat	
					Catching fire	Burn
6,000	0.5	(after 60 min.) 330	(after 70 min.) 660	(after 70 min.) 660	410	660
	2	ditto	(after 10 min.) 330	(after 10 min.) 330	—	—
	8	ditto	ditto	ditto	—	—
10,000	0.5	(after 60 min.) 420	(after 120 min.) 740	(after 120 min.) 740	530	840
	2	ditto	(after 20 min.) 420	(after 20 min.) 420	—	—
	8	ditto	ditto	ditto	—	—
30,000	0.5	(after 60 min.) 640	(after 120 min.) 1000	(after 120 min.) 1000	800	1280
	2	ditto	(after 20 min.) 680	(after 20 min.) 680	—	—
	8	ditto	(after 20 min.) 640	(after 20 min.) 640	—	—

Source: The Japan Association for Preventing Marine Accidents, 'The investigation and study on safety measures of mammoth tankers.'

3-4 Promotion of fire prevention measures of liquified gas tankers

The more the demand for liquified gas increases as a clean, alternative energy for oil, the more frequent LNG tankers pass the Canal. Since LNG is a very dangerous substance, if it is discharged on the sea, catch fire and explodes, the damage to human life and assets will be extremely serious not only in the city areas of Port Said and Suez, but also in the Canal where many other vessels are cruising. Fire must be extinguished early, but even when the spilled LNG does not catch fire, prompt measures such as to notify a ban on the use of fire in the surrounding areas should be taken. At the moment, dry chemical is the only effective substance for extinguishing a fire of LPG and LNG. It is also effective for oil fires. The tug-boats which belong to SCA are not equipped with this effective equipments or substances. In preparation for the transit of LNG or LPG tankers, disaster prevention measures should be established in a hurry. The Japanese tug-boats for escorting liquified gas tankers are obliged to install equipment which is capable of emitting more than 2 tons of dry chemical at the emitting speed of more than 30 kilograms per second.

3-5 Effects of light on vessels during night navigation

When the Canal is doubled, we predict that the search lights of the north and southbound ships may interfere with the vision of ship pilots during night navigation in the section where the east and west channels are close to each other. When the doubling of the Canal is in progress, it may be possible to prevent ships meeting at night by, for example, adjusting the transit schedule. But, when the Canal is completely doubled, it will be impossible to prevent such meetings. Thus, to prevent interference with night vision, the following measures should be taken successively during the stages of improvement.

(1) The use of ship's search lights to illuminate the Canal bank should be limited to the right bank to prevent blinding the oncoming vessels. And, in this case, a dip and an intensity of search light should be further examined.

(2) Design and installation of navigation aids in the Canal can eliminate the need for search lights, but only if the aids are maintained well and left on at night.

(3) When the Canal is doubled completely, the Canal banks can be illuminated by ground facilities.

In the sections where both channels are close, the use of ship's search lights is only a tentative solution. The best method to prevent interference with night vision in the Canal is to replace the search lights with electronic navigation aids.

4. Administration-Management Plan

(1) Maintenance of Information System Under Canal Administration Plan

For the administrative planning of the Canal, analysis of the present situations and future forecast on the transit tonnage, income, finance, etc. are important. In order to perform such things, it is necessary to collect and maintain the needed data, to process and tabulate the data, and to analyse it statistically for future trends. The information system on tonnage transiting through the Canal, which serves as the basis for the administrative planning, uses computerized data processing. This is especially essential because of a large number of vessels.

(2) It is important to analyse the relationship between the international economic data (Major countries' GDP, import-export, and trade flow) and the O/D of cargoes (in order to forecast the transit volume). Also, analysis should be made on the economic relationship to the shipping market, to serve for revenue analysis, etc. In order to make such analysis, it is necessary to utilize computers. For that purpose, such specialists as system planners and programmers should be trained and the data basis fit for computer use developed. At the same time, computer software for the tabulation-processing of data, time series analysis, regression analysis, and analysis of econometric models should be prepared.

With respect to the passage volume data, the following information systems are considered to be important:

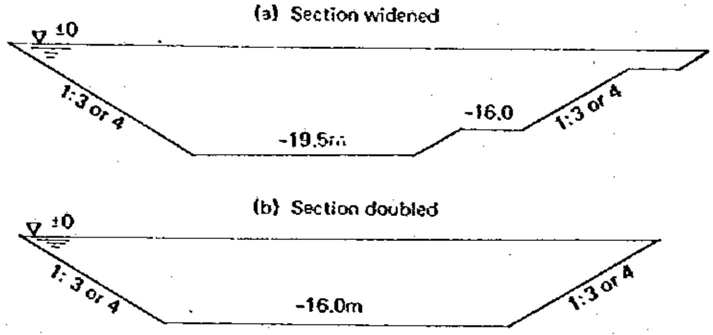
1 Date
2 Kind of vessel
3 Direction
4 Net tonnage registered at Suez Canal authority
5 Deadweight tonnage
6 Cargo
7 Weight and O/D for each cargo

By computerizing the above data, the passage volume analysis as follows may easily be made:

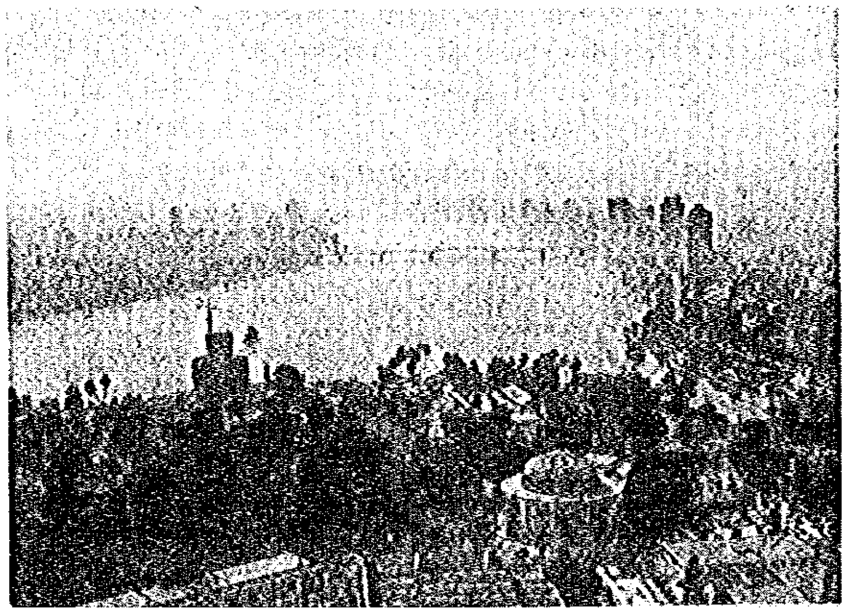
1 Time series analysis of transit tonnage
2 Time series analysis of cargoes
3 Composition of vessel type by type of cargo
4 Composition of vessel type by kind of vessel
5 Load factor by kind of vessels
6 O/D table by kind of cargoes

(3) West Channel Maintenance Dredging Spoil Dump

Profiles of the west channel after completion of the doubling and widening plan are classed into (a) and (b) illustrated below:



The sections (a) are Km16–Km50.5, Km73–Km94.5 and Km145–Km161. The sections (b) are Km1.5–Km16, Km50.5–Km73 and Km114.8–Km161. For the profile (a), there was a water depth of -19.5m against the required water depth of -16.0m, giving an allowance of 3.5m. Thus, if the annual mean siltation is 15cm on the north side of Km161 and 7.5cm on the south side, no maintenance dredging would be required for 23 years for the section Km16.0–Km50.5 and 47 years for the sections Km73.0–Km94.5 and Km145–Km161. Further along the section Km16–Km40, spoil can be dumped on the west side of the canal. For the profile (b), in the section Km1.5–Km16 spoil can be dumped without problem on the west side of the channel, while the section Km114.8–Km133.2 is within the Little Bitter Lake and thus has little siltation. The west side of the channel is adequate for dumping in this location. Thus, the sections where dumping is more difficult are Km50.5–Km73 and Km133.2–Km145. In these sections, the annual mean siltation is assumed to be about 230,000m^3 for the section Km50.5–Km73 and about 80,000m^3 for the section Km133.2–Km145. The excavation sand from the expansion or doubling plans in these sections is to be dumped on the west side. Thus, for both the spoil and the dredgings, the SCA must secure a dump of about 5,000,000m^3 for the maintenance dredging over a 20 year period, and about 2,000,000m^3 for the spoil during construction.



XI. Economic Analysis

PART XI ECONOMIC ANALYSIS

1. Basic Principle and Method of Analysis

The economic feasibility of the Second Stage Development Project, particularly Phase I, will be analyzed in this Part.

Because of the character peculiar to the Suez Canal, this project will not only bring benefits to Egypt but also will have very close relation to the world economy as a whole. However, direct beneficiaries are the operators of ships transiting the Canal as well as the shipowners and the shippers. And these benefits enjoyed by them will be then indirectly spread to many countries in Middle East, Asia, Europe and the Americas which import and export cargoes through the Canal.

Thus, the evaluation of this project must be made not only on the basis of the national economic viewpoint, as done in ordinary projects, but also on the basis of world economics.

As a methodology in making the evaluation, the internal rate of return of the project will be first found and the result will be then compared to the opportunity cost.

The internal rate of return is calculated using Equation (11.1) as shown below:

$$\sum_{i=0}^{n} \frac{B_i - C_i}{(1+r)^i} = 0 \qquad (11.1)$$

where, B_i : Benefit at i-th year

C_i : Cost at i-th year

r : Rate of discount

The value of "r" that satisfies the Equation (11.1) is called an internal rate of return (IRR).

At present, various administrative policies which may deform the free market economy are being taken in Egypt; some of them are the minimum wage law introduced to cope with a high rate of unemployment and various kinds of other aid policies. The economic evaluation of the project is generally performed after converting the data available under such deformed economic situation into those expected under free market economy. This is actually an introduction of the so-called shadow price. However, in this project, since relatively high profitability can be expected, it is not required to examine more real profitability by forcedly introducing such shadow price. Thus, costs and benefits have been calculated without applying the shadow price.

Because this study is a feasibility study, the calculations of costs and benefits were based on various kind of prerequisites. Also, the cost estimate includes uncertain portions such as estimate of dry excavation, which was performed without detailed topographic information. Therefore, 10% of the estimated construction cost is included in the total construction cost as a contingency, so that the cost estimated will be sufficient. An occurrence of an unforeseen situation in the future cannot be completely denied. However, a sensitivity analysis was made for several cases in order to check the effect of such occurrence on the profitability of the project.

2. Evaluation of the First Phase Plan (Phase I Project)

2-1 Evaluation from the viewpoint of national economy

The economic feasibility of Phase I project will be analyzed from Egyptian national economic viewpoint.

2-1-1 Costs

The following items were used as project costs:

1) Initial investment
2) Administrative expenses
3) Operational expenses
4) Maintenance expenses

The initial investment will include costs of civil engineering works such as dry excavation cost, revetment construction cost, dredging cost, transfer cost for railways and roads, and reconstruction of siphon pipes as well as all other relevant costs such as purchasing costs for navigation aids and tugboats.

As a rule, "Schedule 1" shown in Table 9-4-2 of Part IX will be used in determining yearly investment plans for these expenses. Only the increased expenses due to Phase I have been adopted for administrative expenses, operational expenses and maintenance expenses. The details of estimate method for these expenses and amounts are shown in Chapter 1, Part XIII and, thus, they will not be described.

Though the estimate of the initial investment includes the physical contingency, it does not include the cost of a price escalation.

2-1-2 Benefits

The benefits of this project are:

(a) Revenue in foreign currency brought from an increased number of transit ships, as a result of a doubled Canal (that is, toll revenue from the Canal).
(b) Improved safe navigation of ships as a result of doubled Canal.
(c) Continuous employment resulted from construction work for doubling the Canal.

Only the direct benefits are shown above. Egypt will also enjoy other benefits such as:

a) more stable position of Egypt in the world that will be brought by the scheduled upgrading of the Canal in response to the demand of the world, and
b) more favourable balance of payment brought by increased Canal revenue.

(For reference)

Foreign currency receipts	(Price unit:	Mil. USD)
	(1977)	(1992)
Merchandise: Export (fob)	2,888	
Services (net): Travel	660	
Canal	385 →	1,328

Source: Derived from IMF' I.F.S., 1979' and World Bank Report' Arab Republic of Egypt: External Capital Requirement, 1978'.

Concerning the benefit (a), increased Canal revenue expected from Phase I can be considered as benefit. This will be described later in detail.

Concerning the improved safety of navigation of benefit (b), the relief of ships' masters or pilots from mental pressure resulted from reduced number of meetings of convoys in the doubled Canal is actually unmeasurable. However, loss in Canal revenue resulting from Canal closure after occurrence of an accident within the Canal can be anticipated, since large tankers would quickly select the route via the Cape if such an accident occurs. Though these benefits can not be overlooked, as mentioned above, quantifying of the benefits for economic analysis is difficult in this study.

Concerning the continuous employment of benefit (c), a high rate of unemployment presently exists in urban areas of Egypt, and also a high rate of unemployment is anticipated in Ismailia, a city at the center of the Canal, though data for recent years for this city are not available for consideration of existing high rates of unemployment in Cairo and Alexandria, as indicated in Table 11-2-1.

Table 11-2-1 Rate of Unemployment in Different Urban Area 1961, 1970 and 1975

Urban Areas	Rate of Unemployment in 1961 %	Rate of Unemployment in 1970 %	Rate of Unemployment in 1975 %
Cairo	7.5	3.5	4.0
Alexandria	9.2	7.6	7.0
Port-said	10.81	–	–
Ismailia	6.7	–	–
Suez	11.7	–	–

Source: Institute of Developing Economics, Tokyo, Japan. Joint Research Program Series, March, 1979.

At present, it is said that more than 2,500 Egyptian workers are currently being employed by Japanese firms under the First Stage Project. If the Second Stage Project would not begin immediately after completion of the First Stage Project, these local workers will be forced to find other jobs. It seems to be extremely difficult for them to find other job in urban areas where high rates of unemployment exist. For this reason, it is socially very meaningful to start the Second Stage Project immediately after the First Stage Project is over, but there are many difficulties in counting this effect as benefit in the economic analysis. Therefore, this effect will not be counted as benefit in this study.

(1) Principles of benefit estimates

The benefits were estimated based on two principles; first after saturation of capacity of First Stage Development Project, in case that the Second Stage Project is not executed to meet the demand, excess ships will have the same configuration in type and size of ships in each year as that obtained from the demand forecast in Part IV. Second, overflow will occur beginning with the largest ship in sequence to the smaller one for each type of ships.

The benefit corresponding to the former will be defined here as R-1 and other benefit corresponding to the latter will be defined as R-2. It is difficult to forecast here which of these benefits will be more realistic but R-2 seems to reflect a more realistic trend. In actuality, it is more likely that instead of selecting the Cape route beginning with the largest ship of each ships' type, vessels such as ULCCs and VLCCs that have less differences in transportation costs between Cape route and Suez route will switch first to the Cape route.

(2) Estimate of benefits

Method of estimate for R-1 and R-2 is described in "Sensitivity Analysis of Canal Revenue" of Part XII and thus will not be repeated here.

The benefit of each year is an increment of revenue resulted from the Second Stage Project, and was found from the following formula:

Benefit = (Revenue after Phase I) – (Revenue before Phase I)

As reviewed in Parts VI and VII, it is expected that after the completion of the First Stage Project, the saturation of capacity will begin around the year 1981, resulting in waiting of vessels. However the Canal revenue will increase even after that year until it reaches the limit of theoretical capacity if congestion is allowed. On the other hand, it is considered that Canal users will dislike waiting for transit more than several days, and that larger tankers will show more marked tendency of diversions to other route than smaller ships. In actual case, it is considered that tankers will select the Cape route in earlier stage if there is a possibility of waiting at Suez. Though making a forecast for the year when ships begin to select the Cape route is difficult since real data of congestion of ships in Suez Canal in the past are not available, the present study suggests that 50% of all ships concerned may select the Cape route during the years from 1981 when waiting for transit will begin to 1987 when the number of ships will reach the theoretical limit of capacity.

The same situation can be expected also under the Second Stage Project (Phase I). However, it is considered here that the revenue does not increase after 1992 when the number of ships will reach the theoretical limit of capacity as already reviewed for Phase I in Part VI and Part VII in favour of the conservative project evaluation.

The benefits estimated (increase in Canal revenue) on the basis of the above considerations are indicated in Table 11-2-2.

Table 11-2-2 Revenue Increased by Phase I Project (Base Case)

(10^6 \$)

	R-1			R-2		
	Phase-I	1st Stage	Balance	Phase-I	1st Stage	Balance
1980	785.2	785.2	0	785.2	785.2	0
1981	833.1	833.1	0	833.1	833.1	0
1985	1,021.6	927.4	94.2	1,021.6	857.0	164.6
1987	1,121.9	977.5	144.4	1,121.9	885.5	236.4
1990	1,290.6	977.5	311.3	1,290.6	959.3	331.3
1992	1,373.3	977.5	395.8	1,373.2	899.5	473.7
1995	1,373.3	977.5	395.8	1,213.7	825.7	388.0
2000	1,373.3	977.5	395.8	1,015.7	715.5	300.2

In case of R-1, the Canal revenue will not decrease even after reaching the capacity limit for both the First Stage Project and Phase I. In case of R-2, the revenue will gradually decrease after reaching its capacity limit since large vessels which are expected to bring a great deal of revenue to the SCA may probably avoid to transit the Suez Canal. For example, even though the First Stage Project is capable of providing the maximum revenue in 1987 with maximum number of ships allowed to transit by the canal capacity, the revenue will then decrease (with respect to 1987) to 90% in 1990, to 80% in 1995, and to 73% in 2000. This means that the canal revenue will decrease and the SCA may have fatal damages if adequate capacity increase is not provided in response to the increase in demand after the completion of the First Stage Project. On the other hand, large benefits can be expected if appropriate measures are taken in response to the increase in demand.

(3) Internal rate of return

The internal rate of return was estimated from the expenses and benefits shown above with 20 years of project life. The benefits were considered to occur beginning from the next year of work completion year. In case of Phase I, the benefits will begin to occur from 1985 and 1988 since Step 1 for doubling the Canal in section 61 – 95 km will be completed in 1984 and Step 2 in sections 16 – 51 km section and 122 – 135 km be completed in 1987, respectively. Internal rates of return obtained are indicated below:

	R-1	R-2
Internal rate of return	24.2%	28.3%

As far as IRRs are concerned, though a higher value will be expected from R-2 than R-1, it will be safer to make an evaluation on the basis of benefit of R-1 in view of conservative project evaluation.

The internal rate of return of the opportunity cost in Egypt will be approximately 15% as targets of transport projects in recent years in Egypt, as indicated in Table. 11-2-3. The internal rate of return in the case of R-1 is so high that sufficiently high economic feasibility

Table 11-2-3 IRRs of Transport Projects in the Past

Name of Project	Year	IRR	Project Life	Remarks
			years	
Railway Project	1971	13.5%	25	
The Second Railway Project	1975	12%	25	
Suez Canal Expansion Project (1st Stage)	1977	13–16%	20	
The Second Telecommunications Project	1976	12%	20	FRR

Source: Reports by World Bank.

can be confirmed. In view of the characteristics of the Suez Canal that have been represented by its traditional ability to create high profitability in the past, the internal rate of return of this degree should be naturally expected.

2-2 Evaluation from the viewpoint of world economy

As already stated, the Suez Canal as an important international sea lane will contribute not only to Egypt but also to the development of world economy. Therefore, this project must be evaluated on the basis of world economy, too.

2-2-1 Benefits

Since the costs are the same as those for the national economic evaluation, only the benefits for the world economic evaluation will be specially estimated. The effects of doubling the Canal on the world economy are:

(a) Increase in the Canal capacity will assure the transit of increasing number of ships, thus avoiding cost increase due to turning round the Cape by such increasing number of ships.

(b) The doubled Canal will allow non-stop transit of even the southbound ships so that loss time of ships due to waiting within the Canal can be reduced.

(c) Since the doubled Canal is capable of reducing the number of meeting points by southbound and northbound ships, the difficulty and anxiety during ship maneuvering can be avoided, thus preventing the possible occurrence of accidents.

Concerning benefit (c) of improved safety during the transit of ships, this benefit cannot be measured as the same as the case of national economic evaluation, so that it will not be counted as benefit in this study. Benefit (a) is calculated from the increase in transportation cost of ships over the Canal capacity and forced to use the Cape route. The details of this estimate are described in Part XII "Sensitivity Analysis of Canal Revenue". As same as the national economic evaluation, the overflowed ships were reviewed for two cases; the first case is that overflowed ships will have the same configuration in type and size of ships in each year as that obtained from the demand forecast in case that the Second Stage Project is not executed to meet the demand (called B-1). The second case is that the overflow will occur beginning with the largest ship in sequence to the smaller one for each type of ship (this is called B-2). It is estimated that the Canal capacity after completing the First Stage Project, will be filled in 1981, then overflow of ships will begin and the Canal traffic will reach the theoretical limit of capacity in 1987, according to the forecast. However, as same as the case of national economic analysis, the benefit was estimated on the assumption that 50% of all ships will turn round the Cape while the remaining 50% of ships transit the Canal even though they have to wait (refer to Table 11-2-4).

Table 11-2-4 Forecast Benefit (Base Case)

(10^6 $)

	B-1			B-2		
	Turn Round Cost	Time Saving Cost	Total	Turn Round Cost	Time Saving Cost	Total
1980	0	0	0	0	0	0
1981	0	0	0	0	0	0
1985	304.2	2.7	306.9	437.5	2.7	440.2
1987	471.4	37.0	508.4	647.8	37.0	684.8
1990	1,052.3	41.4	1,093.7	1,518.2	41.4	1,559.6
1992	1,348.0	44.2	1,392.2	1,935.3	44.2	1,979.5
1995	1,348.0	44.2	1,392.2	1,816.7	44.2	1,860.9
2000	1,348.0	44.2	1,392.2	1,650.0	44.2	1,694.2

Concerning the Second Stage Project (Phase I), an increase in benefits can be expected since the number of ships transiting the Canal will continue to increase even after 1981 when the waiting will begin until it reaches the theoretical capacity limit. However, this increase in benefit is not taken into account in favour of the conservative evaluation. Benefit (b) of time saving is counted based upon the effect of time shortened by the non-stop transiting of southbound ships, and is exactly the same as that used for Paragraph 2-2 of Part VI. Since the effect of time saving is to be enjoyed by all southbound ships, the benefit was estimated for general cargo ships with an average ship size of 10,000 DWT. Refer to Paragraph 2-2 of Part VI for detail. These benefits are shown in Table 6-3-5.

2-2-2 Internal rate of return

As same as the case of economic evaluation from the viewpoint of national economy, the internal rates of return were estimated for the project life of 20 years. The benefit is considered to begin in the year after the completion of the project and, the benefits are considered to begin to arise in 1985 and 1988 respectively for Phase I, since step 1 for doubling the Canal in Km 61 – 95 section will be completed in 1984 and step 2 in Km 16 – 51 and Km 122 – 135 sections be completed in 1987. The internal rates of return obtained are shown below.

	B-1	B-2
Internal rate of return	49.8%	59.0%

Internal rate of return of 50% was obtained as the effect of the doubled canal on the world economy, by which a high economic effect of the project has been confirmed. In case of B-1, national economic IRR of 24.2% was included within the world economic IRR, so that the remaining 25.6% will be the IRR representing the benefit enjoyed by ship operators, ship-owners and shippers and indirectly by world economy as a whole. A similar result was obtained for B-2 in which an IRR of 28.3% was expected for Egypt and of 30.7% for the world economy.

2-3 Sensitivity analysis

Occurrence of an unforeseen situation at the execution stage of this project is always anticipated and, thus, a sensitivity analysis was conducted to check the economic viability of the project. The sensitivity analysis was performed for the following three cases:

(a) Case where traffic demand fluctuates
(b) Case where construction cost increases
(c) Case where earlier completion of work occurs

2-3-1 Case of fluctuation in traffic demand

For the case of fluctuation in demand, national economic IRR corresponding to Low Case and High Case used in Forecast of Suez Canal Traffic of Part IV were calculated. The same method used in Paragraph 11-2-1 was adopted in considering costs, benefits and period of calculation. The benefits were calculated for R-1 and internal rates of return obtained are as shown below.

	Low Case	High Case
Internal Rate of Return	18.1%	28.0%

IRR of 18.1% almost equivalent to the opportunity cost was obtained even for Low Case, from which the feasibility of this project can be fully confirmed even though the world economy grows at a lower rate than expected. If the demand shifts to High Case, the profitability will naturally increase, but users may be forced to wait for transit, so that earlier doubling of the Canal is more desirable in this case.

2-3-2 Case of increase in construction cost

In the cost estimates, the volume of dry excavation, for instance, was calculated with no available topographic maps suited to such estimate. Therefore, 10% of each work cost was included in the estimated cost as a physical contingency to avoid the shortage in funds. However, we cannot completely deny the possibility of finding bedrock at deep locations. Thus, national economic IRR was estimated taking account of an expected increase in construction cost due to such unforeseen situations. The range of increase in construction cost for this assumption was considered to be between 10% and 30%. R-1 was used for the estimate of benefit. The internal rates of return obtained are indicated below.

	10% Increase of Cost	20% Increase of Cost	30% Increase of Cost
Base Case	22.8%	21.5%	20.3%
High Case	24.6	23.1	21.8

If the construction cost increases by 10%, IRR tends to decrease by 1% to 1.5%. For instance, if the construction cost increases by 30%, then IRR decreases approximately by 4% resulting in 20.3% IRR, but this is still sufficiently at high level with which the feasibility of the project can be fully confirmed.

2-3-3 Case where earlier completion of work is selected

Since there is a possibility that the demand will increase at the rate of High Case, national economic IRR was estimated when Phase I work is completed earlier than scheduled time (Schedule-1 of the construction program). For this case of earlier completion of work Schedule-2 of the construction program was proposed in Chapter 3 of Part IX. According to the result, in Schedule-2, both Step 1 and Step 2 of Phase I will be completed in 1984, at the same time. If Phase I is completed in 1984, shortage in capacity will not occur even though the demand may increase at the rate of the High Case, so that waiting of transit can be avoided without losing the benefits for Egypt. In this case, R-1 was used, and the benefits for two cases when the demand increased at the rate of Base Case and High Case were estimated and the investment program corresponding to Schedule-2 was adopted for the costs. Internal rates of return obtained are shown below:

	Base Case	High Case
Schedule-2	22.1%	25.3%

For the demand of Base Case, the IRR for Schedule-2 will be naturally lower than that for standard Schedule-1 but the difference is only 2%, which means that IRRs are not so different each other. On the other hand, if the demand increases at the rate of High Case, IRR for Schedule-2 will become higher than that of Base Case of Schedule-1. Naturally, IRR may be lower than that of High Case of Schedule-1, but the difference is very small. As can be seen from the above analysis, the Schedule-2 is a feasible program. It is desirable to users of the Canal to carry out the construction works based on the Schedule-2 in order to meet the demand increase at the rate of High Case. A main interest of users is to avoid an unexpected waiting of transit due to insufficient transit capacity of the Canal.

3. Evaluation of the Second Stage Development Project

The economic evaluation of Phase I of the Second Stage Development Project was made in the foregoing chapter, and economic evaluation of the entire Second Stage Development Project will be made in this chapter, as references for reviewing construction program after Phase I.

3-1 Evaluation from the viewpoint of national economy

Economic IRR for the whole of the Second Stage Project was estimated by using the same method as made in Chapter 2. However, the period of calculation was assumed to be 20 years after the completion of Phase I. Thus, the last year of the Project life is the same as that of Phase I. IRR obtained for each construction program is indicated below. R-1 case was used for benefits.

	Base Case	High Case
Schedule 1	23.8%	28.2%
Schedule 2	20.4%	25.4%
Schedule 3*	19.3%	24.6%

* Schedule-3 was proposed in Chapter 3 of the Part IX in order to complete the doubling works earlier than Schedule-2.

This result shows that the IRR of Schedule-1 is similar to that of Phase I, if the capacity of the Canal is gradually increased in response to the demand. IRRs of Schedule-2 and Schedule-3 are slightly lower than that of Schedule-1, but the difference is small and adequate investment effects can be expected for both Schedule-2 and Schedule-3.

3-2 Evaluation from the viewpoint of world economy

As in the foregoing chapter, the world economic IRR for the Second Stage Project was estimated using the same method as in Paragraph 2-3 in this Part. As benefits, the reduction in waiting time at Port Said and Suez (10 hours) induced by completely doubled Canal was adopted in addition to benefit B-1 defined in 2-2-1. The period of estimate is the same as that of the evaluation from the viewpoint of national economy.

IRR obtained for each construction program is indicated below.

	IRR
Schedule 1	49.0%
Schedule 2	42.4%
Schedule 3	40.4%

In this case, IRR similar to that of Phase I can be expected for Schedule-1, but IRRs for Schedule-2 and Schedule-3 are slightly lower because of investment preceding the demand.

Also, another IRRs for the Second Stage Project were estimated without counting B-1 as benefit. This benefit is based upon the increased revenue derived from the Second Stage Project as a direct benefit of Egypt and upon the reduced time due to a double Canal, and reduction in waiting time at Port Said and Suez (10 hours) resulted from a completely doubled canal as world economic benefit. The result of the estimate is shown below:

	Base Case	High Case
Schedule 1	26.3%	30.2%
Schedule 2	24.0%	27.3%
Schedule 3	23.4%	26.6%

In this case, the relations among Schedules-1, 2, and 3 are the same as those obtained in previous case. Because of a large benefit of increase in revenue, a tendency similar to that of the evaluation from the viewpoint of national economy was found.

Costs and benefits calculating IRRs are as shown in Tables.11-A-1~11-A-29.