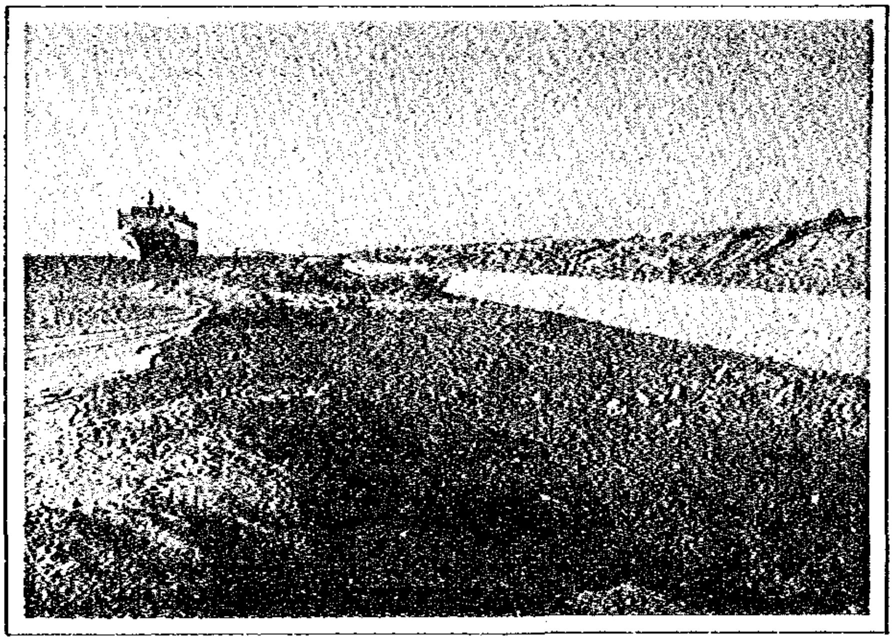
PART V. RISK ANALYSIS



East Bank of Ballah West Branch

PART V RISK ANALYSIS

V-1 Setting up Conditions

(1) Civil Engineering Factors

1) Canal Topography

The current profile of the Suez Canal for risk analysis is set in accordance with the results of the review study and of its evaluation as shown in Table II-1-(1)-1.

As for the future profile of the Canal, there are many alternatives such as the widening deepening plan scheduled by SCA, the doubled channels plan recommended by the former Japanese mission, and other plans including modifications of the two plans mentioned above. Table V-1-(1)-1 shows the future Canal topography in the same form as the current Canal data in Table II-1-(1)-1. These widths, depths and curvatures are set on the basis of the widening deepening plan taking into account the execution plan which has already been partially carried out by SCA. The reason why the dimensions described in the Table are taken as the premises, is that the plan is the most likely to be put into effect, and thus is most suitable for risk analysis comparison between the current Canal and the future Canal.

The Canal profile during the Second Stage Development Project changes according to such working factors as speed, location and shifting of working vessels. These factors are not scheduled at the present time. In this report, due to such circumstances, the premises for risk analysis on safety during the expansion works are taken as being the same as those of the current Canal.

Fig. V-1-(1)-1 shows the cross sections of the current and future Canal comparatively.

2) Execution Conditions

The number of working vessels in the Canal is the most important factor for risk analysis. According to the Second Stage Development Project of SCA, the total amount of soil volume to be dredged is roughly calculated at 336.2 million M^3 including the volume to be dredged in the anchorage area of Great Bitter Lake. Due to varied soil conditions, various types of dredgers with different capacities will actually be used during the project. However, in the study an 8 thousand H.P. class dredger is taken as the standard vessel. According to the results of the First Stage Development Project, such a dredger usually has a dredging capacity of 435 thousand m^3 per month in the case of common soil conditions, and so the number of dredgers working at the same time in the Canal comes to about 20 assuming that the dredging works are to be completed in about three years.

This estimate of 20 dredgers is used for risk analysis on safety during the Second Stage Development Project.

About maintenance dredging, as the probability of accidents occurring in the current Canal already includes the possibility of accidents with maintenance dredgers, the conditions of the maintenance work during the Second Stage Development Project are regarded as the same as at present.

Table V-1-(1)-1 Width, Depth and Curvature of the Canal by Hm and Km (Future Profile)

Notes to Table V-1-(1)-1

1. The left half of the Table shows the dimensions of the West Channel and the right half shows those of the East Channel.
2. The dimensions, for sections of the Canal not separated into two channels, are written on the left side.
3. The numerals marked by an asterisk (*) are not provided by SCA, but are extrapolated from SCA data for this study.
4. Location: The chart reads from north to south.
    1) The locations indicate the distances based on the "Kilometer Base Line" along the East and West Channels.
    2) The point of Hm 0.00 in the Mediterrenean Sea is the same as of Km 0.000 and the point Hm 0.00 in the Red Sea is the same as Km 162.250.
5. Changing point
    1) This column shows the locations where some dimension of the Canal changes.
    2) The "from" means the beginnings of the change and the "to" means the end of the change (proceeding from north to south).
    3) In the case of putting the same numerals in both "fron" and "to", it means that the position is a point where some dimension changes its value abruptly.
6. Width:
    1) Widths listed are the bottom widths of channels at the planned depth and not the distance between the 11 m depth lines.
    2) A pair of lines between sections represents the sides of a channel.
    3) Calculated widths (marked *) take into consideration the slopes of banks.
7. Depth:
    1) The "Plan" shows the depths planned for the First Stage Development Project and the "Center" shows the results of the sounding conducted at the center line of the Canal on June 4, 1983.
    2) A pair of lines between sections represents the bottom and the water surface of the Canal.
8. Curvature:
    1) Curvatures are expressed as the radius of the curves.
    2) The "L" indicates that the channel curves to the left and the "R" to the right, when facing south.
    3) The "K-B", "E-Th" and "W-Th" show the curvatures of the "Kilometer Base Line", "East Theoretical Line" and "West Theoretical Line" respectively.

Location (Hm, Km)	Section (Hm, Km) from	Section (Hm, Km) to	Width (m)	Depth (m)	Curvature (R: m)	Location (Hm^{E}, Km^{E})	Section (Hm, Km) from	Section (Hm, Km) to	Width (m)	Depth (m)	Curvature (R: m)
						220.00$^{\text{Hm}}$	220.00	220.00	700.00	25.00	
						210.00					
						200.00					
						190.00					
						180.00					
						170.00					
						160.00					
						150.00					
						140.00					
						130.00					
						120.00					
						110.00					
						100.00					
	Juncture of Port Said Approach Channel					90.00					
80.00$^{\text{Hm}}$	80.00	80.00	550.00	13.00		80.00					
70.00						70.00					
60.00						60.00					
50.00						50.00					
40.00						40.00					
30.00						30.00					
20.00						20.00					
10.00	*10.00		*143.00			10.00					
0.000$^{\text{Km}}$		*0.000		13.00		0.000 km					
1.000	1.000		143.00	15.00		1.000					
	*1.500				*K-B 3,060.00L		1.333		120.00	25.00	

Location (Hm, Km)	Section (Hm, Km)		Width (m)	Depth (m)	Curvature (R: m)	Location (Hm^E, Km^E)	Section (Hm, Km)		Width (m)	Depth (m)	Curvature (R: m)
	from	to					from	to			
								*1.348	150.00	23.50	
2.000						2.000					
3.000						3.000					
4.000						4.000					
5.000						5.000					
6.000						6.000					
7.000						7.000					
8.000						8.000					
9.000						9.000					
10.000						10.000					
11.000						11.000					
12.000						12.000					
13.000						13.000					
14.000						14.000					
15.000						15.000					
							*15.120	*15.120	150.00	23.50	
								*15.470	220.00	23.50	
16.000						16.000	Juncture of Port Said Bypass				
	16.500	16.500	143.00	15.00							
		16.663	131.00	19.00							
17.000				19.00		17.000					
		*17.045		23.50							
18.000	Juncture of Port Said Bypass					18.000					
19.000			135.00	23.50		19.000			135.00	23.50	
20.000											

Location (Hm,Km)	Section (Hm,Km)		Width (m)	Depth (m)	Curvature (R: m)	Location (Hm^E, Km^E)	Section (Hm,Km)		Width (m)	Depth (m)	Curvature (R: m)
	from	to					from	to			
21.000											
22.000											
23.000											
24.000											
25.000											
26.000											
27.000											
28.000											
29.000											
30.000											
	30.427	30.427	135.00	23.50							
31.000											
32.000											
	32.350	32.350	234.00	23.50							
	32.950	32.950	234.00	23.50							
33.000											
34.000											
35.000											
		35.110	135.00	23.50							
36.000											
37.000											
38.000											
39.000											
40.000											
41.000											

Location (Hm, Km)	Section (Hm, Km)		Width (m)	Depth (m)	Curvature (R: m)	Location (Hm^E, Km^E)	Section (Hm, Km)		Width (m)	Depth (m)	Curvature (R: m)
	from	to					from	to			
42.000											
43.000											
44.000											
45.000											
46.000											
47.000											
48.000											
49.000			135.00	23.50							
	49.512		135.00	23.50			49.512	49.512	135.00	23.50	*E-th 10,993.70L
	49.778				*W-th 11,023.32R						
50.000						50.000					
51.000	Juncture of Ballah Bypass					51.000	Juncture of Ballah Bypass				
	51.477	51.477	70.00	23.50			51.449	51.449	135.00	23.50	
	51.527	51.527	110.00	18.50			51.737				W-th 24,551.27L
	51.800	51.800	110.00	18.50			51.785				*E-th 10,993.7L
		51.830	134.00	15.50							
52.000						52.000					
	52.054				E-th 4,840.00L						
	52.405				W-th 3,080.00L						
	52.497				K-B 1,969.00L						
	*52.900	*52.900	*164.00								
53.000						53.000					
		53.069			K-B 1,969.00L						
		53.298			W-th 3,080.00L						
		53.512			E-th 4,830.00L						
54.000						54.000					

Location (Hm, Km)	Section (Hm, Km)		Width (m)	Depth (m)	Curvature (R: m)	Location (Hm^E, Km^E)	Section (Hm, Km)		Width (m)	Depth (m)	Curvature (R: m)
	from	to					from	to			
		54.098	134.00								
55.000						55.000					
56.000						56.000					
	56.871	56.871	134.00		E-th 4,830.00L						
57.000						57.000					
	57.238				W-th 3,125.91L						
	57.457				K-B 1,969.00L						
	*57.860	*57.860	164.000								
58.000						58.000					
	58.211				K-B 1,969.00L						
	58.429				W-th 3,044.91L						
	58.797				E-th 4,830.00L						
59.000						59.000					
		59.269	134.00					59.895	135.00	23.50	
	*59.870		134.00	15.50			Juncture of Ballah Bypass				
	59.900	59.900		18.50							
60.000						60.000					
	60.309			18.50	W-th 4,000.00R						
		60.800	134.00	23.50							
61.000		Juncture of Ballah Bypass				61.000					
	61.125				K-B 2,100.00R						
	61.324				*E-th 5,015.00R						
62.000						62.000					
	62.707				K-B 2,100.00R						
63.000						63.000					

Location (Hm,Km)	Section (Hm,Km)		Width (m)	Depth (m)	Curvature (R: m)	Location (Hm^E,Km^E)	Section (Hm,Km)		Width (m)	Depth (m)	Curvature (R: m)
	from	to					from	to			
	63.314	Juncture of Ballah Bypass			W-th 4,000.00R		Juncture of Ballah Bypass				
	63.419				*E-th 5,015.00R						
64.000						64.000					
	64.514		150.00	23.50			64.514		150.00	23.50	
65.000											
66.000											
67.000											
68.000											
69.000											
70.000											
71.000											
		71.146	150.00	23.50							
	71.964		/ \ 160.000	23.50	*E-th 6,235.00R						
					W-th 6,000.00R						
72.000											
73.000											
	73.103				K-B 2,001.00R						
74.000											
	74.192	74.192			*E-th 6,235.00R						
					W-th 6,000.00R						
					*E-th 5,765.00L						
					W-th 6,000.00L						
	74.300	74.300			K-B 2,011.00R						
					W-B 2,157.42L						
75.000											

Location (Hm,Km)	Section (Hm,Km) from	Section (Hm,Km) to	Width (m)	Depth (m)	Curvature (R: m)	Location (Hm^E,Km^E)	Section (Hm,Km) from	Section (Hm,Km) to	Width (m)	Depth (m)	Curvature (R: m)
		75.311	160.00	23.50	*E-th 5,765.00L						
					W-th 6,000.00L						
		75.328			K-B 2,157.42L						
	75.948				K-B 2,110.15R						
76.000											
	76.033				W-th 2,375.55R						
	*76.050	*76.050	*160.00	23.50			*76.050	*76.050	*160.00	23.50	
	Juncture of Lake Timsah Bypass						76.557	Juncture of Lake Timsah Bypass			*E-th 4,765.00L
							76.578				W-th 5,000.00
	*76.940	*76.940	*135.00	*13.50			*76.910	*76.910	160.00	23.50	
77.000						77.000					
	77.150				E-th 3,120.00R						
		77.253			K-B 2,110.15R						
		77.371			W-th 2,375.55R						
	77.653				K-B 1,261.00L						
	77.672		*209.58								
	77.912				E-th 2,001.50L						
78.000						78.000					
							78.400		160.00	23.50	
								78.900	160.00	23.50	
79.000			*275.000			79.000					
		79.649	175.000		K-B 1,261.00L						
	79.943	79.943	*97.00		E-th 2,001.50L						
80.000						80.000			*285.00		
		80.313	*97.00				80.300		*515.00		

Location (Hm, Km)	Section (Hm, Km)		Width (m)	Depth (m)	Curvature (R: m)	Location (Hm^E, Km^E)	Section (Hm, Km)		Width (m)	Depth (m)	Curvature (R: m)
	from	to					from	to			
	80.385		*83.00				Juncture of Lake Timsah Bypass				
81.000						81.000					
		81.140	*83.00	*13.50							
82.000	Jancture of Lake Timsah Bypass					82.000					
	*82.576	*82.576	160.00	23.50			*82.576	*82.576	160.00	23.50	*E-th 4,765.00L
83.000											
84.000											
85.000											
	85.027	85.027	160.00	23.50	*E-th 5,235.00R						
					W-th 5,000.00R						
	85.604				K-B 2,511.00R						
86.000											
	86.300		160.00	23.50	K-B 2,511.00R						
		86.782									
87.000											
		87.414	160.00		*E-th 5,235.00R						
					W-th 5,000.00R						
88.000											
	88.814		136.25	23.50							
89.000											
90.000											
91.000											
92.000											
		92.950	136.25	23.50				92.950	136.25	23.50	
93.000	Juncture of Deversoir Bypass					93.000	Juncture of Deversoir Bypass				

Location (Hm,Km)	Section (Hm,Km)		Width (m)	Depth (m)	Curvature (R: M)	Location (Hm^E,Km^E)	Section (Hm,Km)		Width (m)	Depth (m)	Curvature (R: m)
	from	to					from	to			
94.000						94.000					
95.000			*97.00	23.50		95.000			*257.55	23.50	
	*95.063		*135.60	17.25			95.250		*224.00	23.50	
		95.400	*135.60	17.25				95.400	175.00	23.50	
	95.418		*144.80	15.50							
96.000						96.000			175.00	23.50	
97.000						97.000					
				Great	Bitter	Lake					
98.000						98.000					
99.000						99.000					
		99.700	144.80	15.50							
100.000						100.000					
	100.200		144.80	15.50							
		*100.210	*146.66	14.50							
101.000						101.000					
	101.050		*454.00				101.050	101.050	175.00	23.50	
102.000						102.000					
							102.600	102.600	115.00	23.50	E-th 5,000.00L
							*102.615	*102.615	124.00	22.00	
103.000						103.000					
104.000						104.000					
	104.160		229.00				104.160	104.160	434.00	22.00	
105.000						105.000					
								105.250	340.00	22.00	*E-th 5,000.00L
106.000						106.000					

Location (Hm, Km)	Section (Hm, Km)		Width (m)	Depth (m)	Curvature (R: m)	Location (Hm^E, Km^E)	Section (Hm, Km)		Width (m)	Depth (m)	Curvature (R: m)
	from	to					from	to			
107.000						107.000					
108.000						108.000					
109.000						109.000					
110.000						110.000					
111.000						111.000					
112.000						112.000					
							*112.820	*112.820	340.00	22.00	
113.000						113.000					
							113.200	113.200	401.00	22.00	
							*113.205	*113.205	*401.40	22.50	
114.000						114.000					
	114.200	114.200	229.00	14.50			114.100	114.100	*498.60	22.50	
	114.750	114.750	439.00	14.50			114.200	114.200	475.00	23.50	
	114.957	114.957	389.00	14.50				114.800	195.00	23.50	
115.000						115.000					
	115.560	115.560	147.00	14.50			115.134		130.00	23.50	
	115.570	115.570	143.00	15.50							
116.000						116.000					
117.000						117.000					
118.000						118.000					
119.000						119.000					
120.000						120.000					
121.000						121.000					
								121.800	130.00	23.50	
							121.936				*E-th 5,005.00R

Location (Hm, Km)	Section (Hm, Km)		Width (m)	Depth (m)	Curvature (R: m)	Location (Hm^E, Km^E)	Section (Hm, Km)		Width (m)	Depth (m)	Curvature (R: m)
	from	to					from	to			
122.000						122.000					
	*122.020	*122.020	143.00	15.50			122.100	122.100	140.00	23.50	
		122.100	95,00	*23.50			Juncture of Kabrit Bypass				
	122.449				W-th 4,000.00R						
	122.780				K-B 3,000.00R						
123.000						123.000					
124.000	Juncture of Kabrit Bypass					124.000					
125.000						125.000					
		125.004			K-B 3,000.00R						
		125.497			W-th 4,000.00R						
	125.507	125.507	160.00	23.50	*E-th 5,005.00R			125.507	160.00	23.50	
126.000											
127.000											
128.000											
129.000											
	129.499				*E-th 5,235.00R						
					W-th 5,000.00R						
130.000											
	130.077				K-B 2,620.65R						
131.000											
		131.357			K-B 2,620.65R						
	131.975	131.957	160.00	23.50	*E-th 5,235.00R						
					W-th 5,000.00R						
132.000											
133.000											

Location (Hm, Km)	Section (Hm, Km)		Width (m)	Depth (m)	Curvature (R: m)	Location (Hm^E, Km^E)	Section (Hm, Km)		Width (m)	Depth (m)	Curvature (R: m)
	from	to					from	to			
134.000											
	134.544		130.00	23.50							
135.000											
136.000											
137.000											
138.000											
139.000											
140.000											
141.000											
142.000											
143.000											
144.000											
		144.714	130.00	23.50							
145.000											
	145.313				W-th 8,790.60L						
	145.631				K-B 3,000.00L						
	145.915	145.915	*157.00	23.50							
146.000											
		146.041			K-B 3,000.00L						
		146.512			W-th 8,790.60L						
147.000											
	147.146	147.146	130.00	23.50							
148.000											
149.000											
150.000											

Location (Hm, Km)	Section (Hm,Km) from	Section (Hm,Km) to	Width (m)	Depth (m)	Curvature (R: m)	Location (Hm^E, Km^E)	Section (Hm,Km) from	Section (Hm,Km) to	Width (m)	Depth (m)	Curvature (R: m)
151.000											
152.000											
153.000											
	153.524	153.524	130.00	23.50							
154.000											
	154.724	154.724	160.00	23.50	*E-th 5,235.00R						
					W-th 5,000.00R						
	154.987				K-B 3,011.00R						
155.000											
		155.646			K-B 3,011.00R						
		155.724			*E-th 5,235.00R						
		155.827			W-th 5,000.00R						
156.000											
	156.274				*E-th 5,235.00R						
					W-th 5,000.00R						
157.000											
	157.006				K-B 3,200.00R						
		157.550	160.00	23.50							
158.000											
	158.300	158.300	*170.00	23.50							
159.000											
		159.327			K-B 3,200.00R						
		159.998	160.00		*E-th 5,235.00R						
					W-th 5,000.00R						
160.000											

Location (Hm, Km)	Section (Hm, Km)		Width (m)	Depth (m)	Curvature (R: m)	Location (Hm^E, Km^E)	Section (Hm, Km)		Width (m)	Depth (m)	Curvature (R: m)
	from	to					from	to			
161.000											
		161.050	160.00	23.50							
162.000											
162.250Km 0.00Hm	162.250 0.00	162.250 0.00	276.00	23.50							
	1.00	1.00	*285.00	23.50							
	3.09	3.09	265.00	23.50							
10.00											
	19.00	19.00	265.00	23.50							
20.00											
	21.00	21.00	285.00	23.50							
	*22.08	*22.08	265.00	23.50							
30.00											
40.00											
50.00											
60.00											
70.00											
80.00											
		80.50	265.00	23.50							

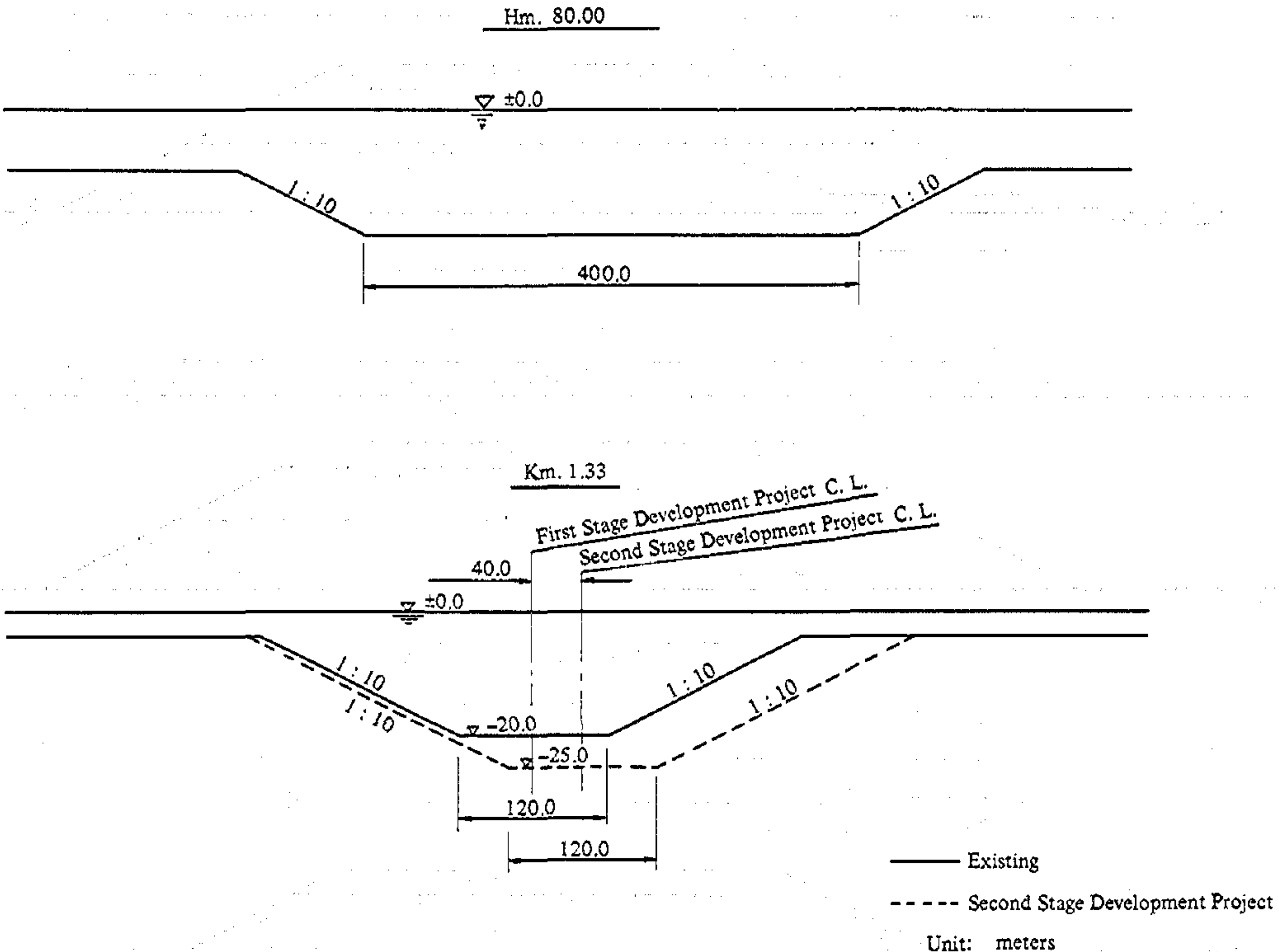
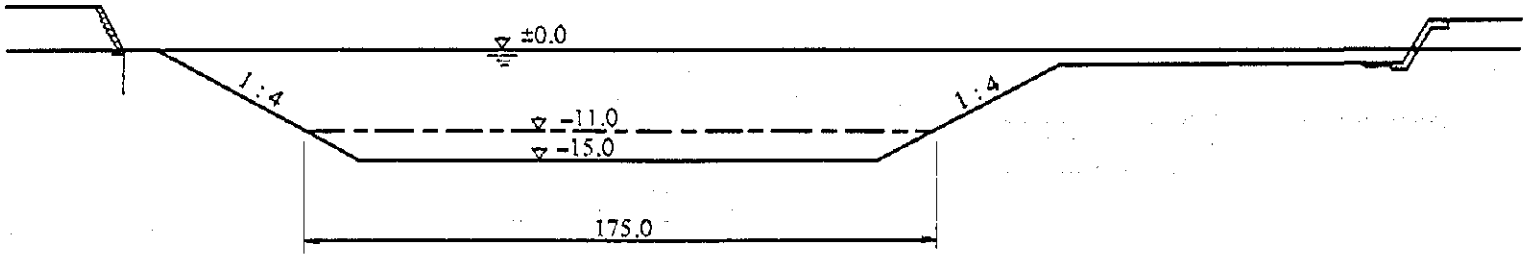
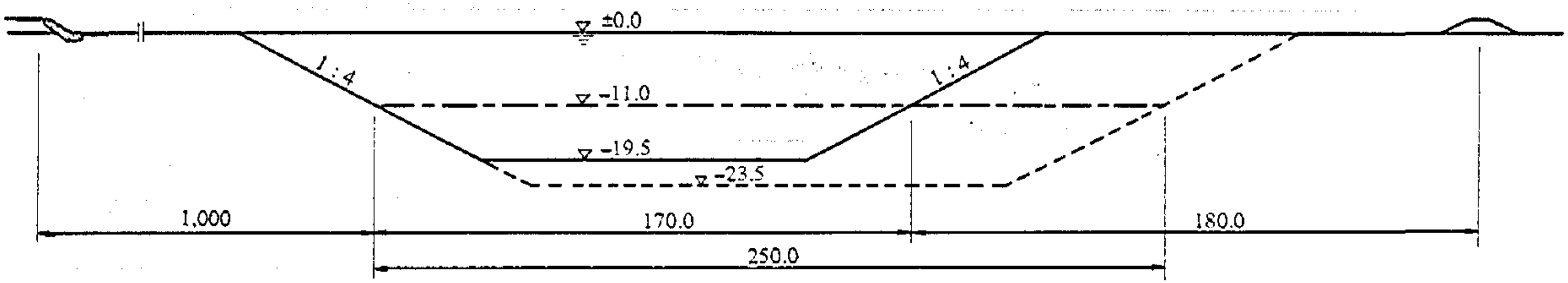


Fig. V-1-(1)-1 Standard Cross Section

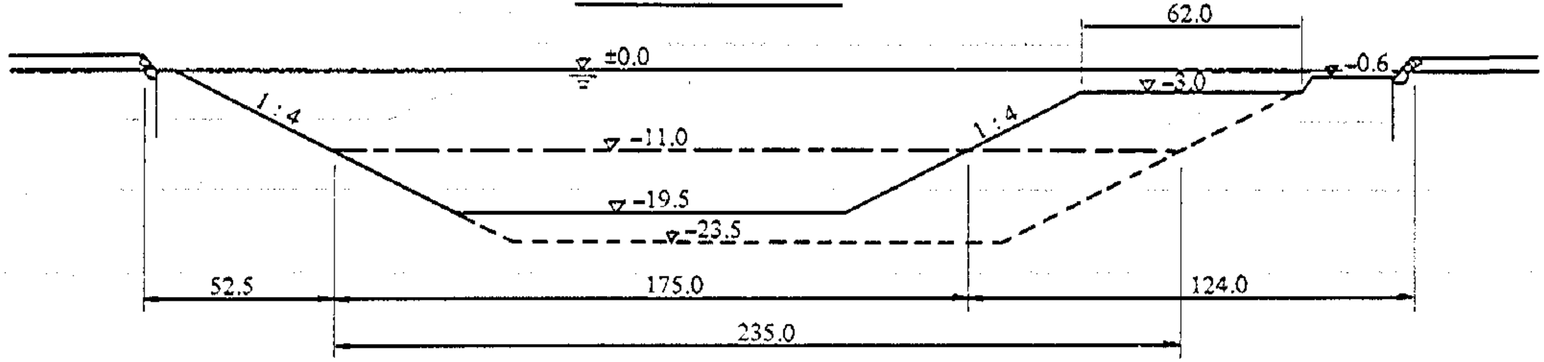
Km 1.00 ~ Km. 16.50 (West Branch)



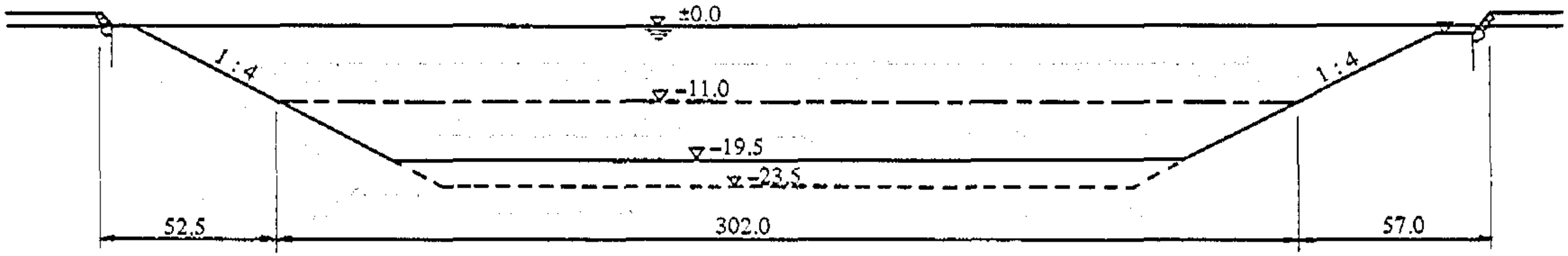
Km 1.348 ~ Km 15.12 (East Branch)



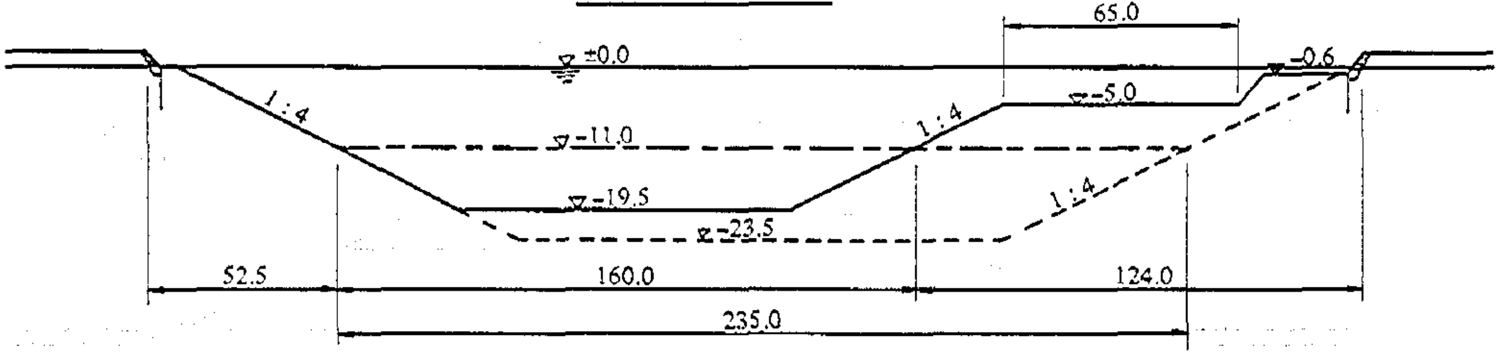
Km. 19.00 ~ Km 30.427



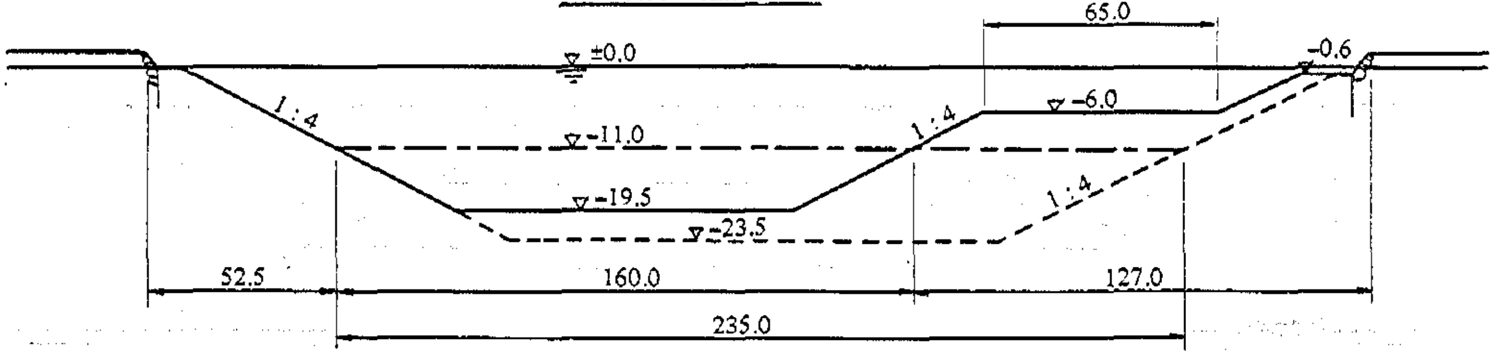
Km 32.35 ~ Km 32.95



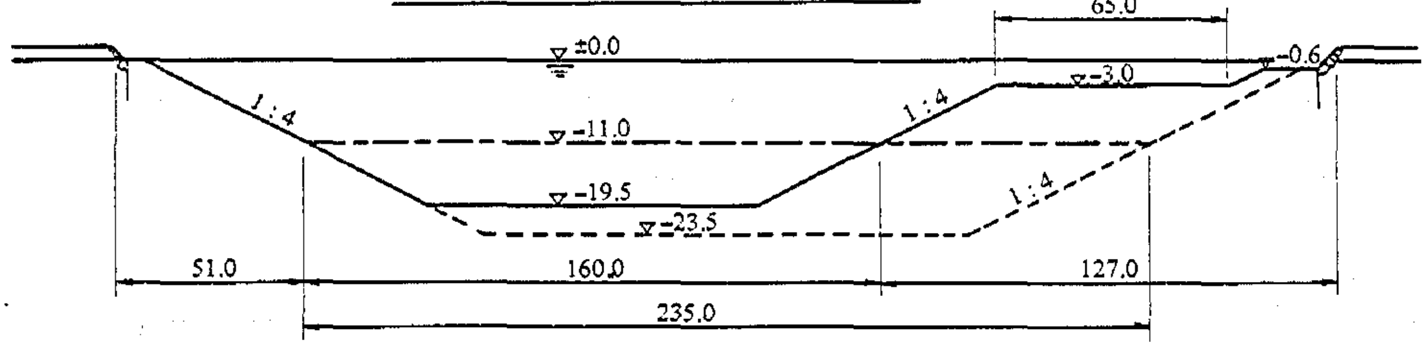
Km 35.110 ~ Km 42.00



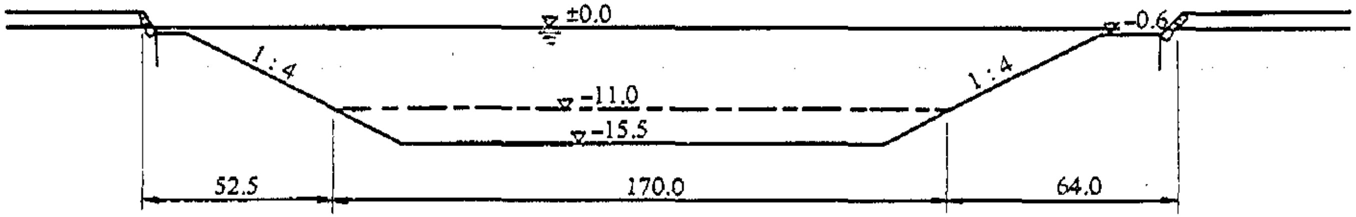
Km 45.00 ~ Km 49.512



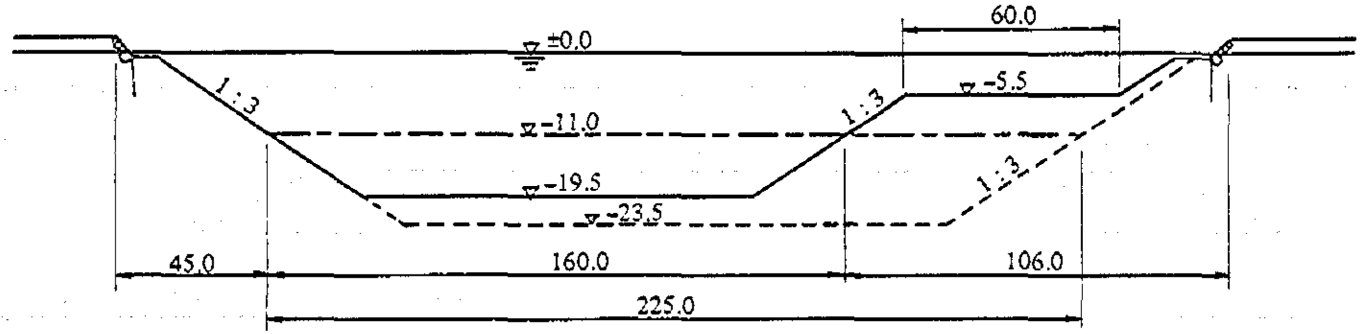
Km 51.785E ~ Km 59.895E (Ballah East Branch)



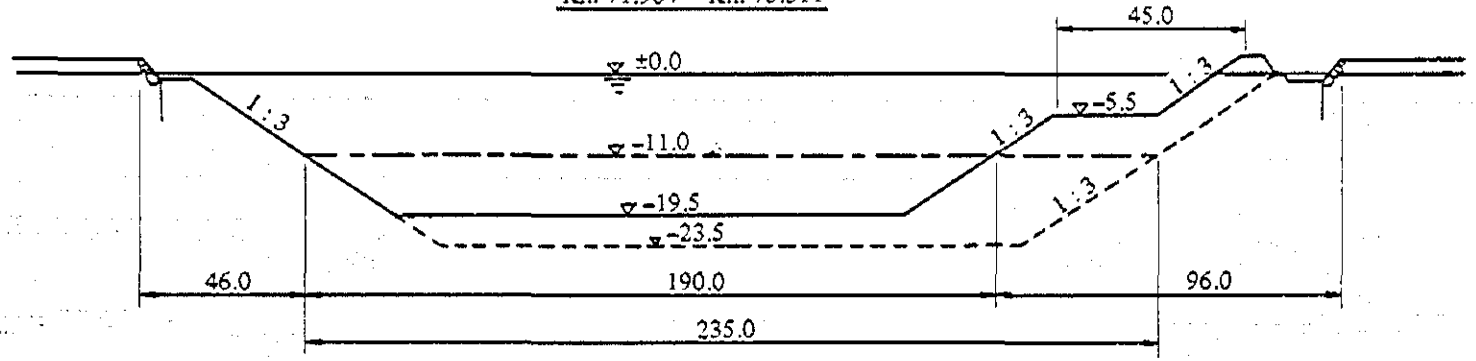
Km 54.098 ~ Km 56.871 (Ballah West Branch)



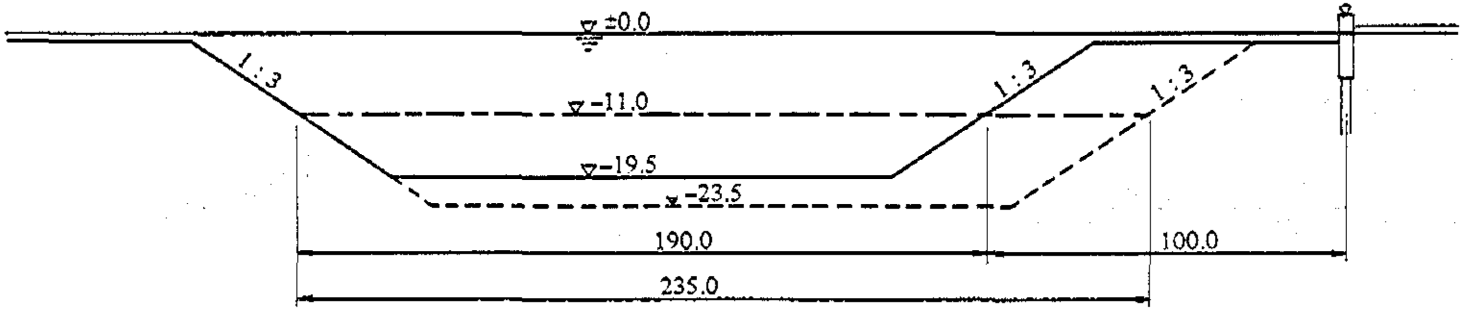
Km 64.514 ~ Km 71.146



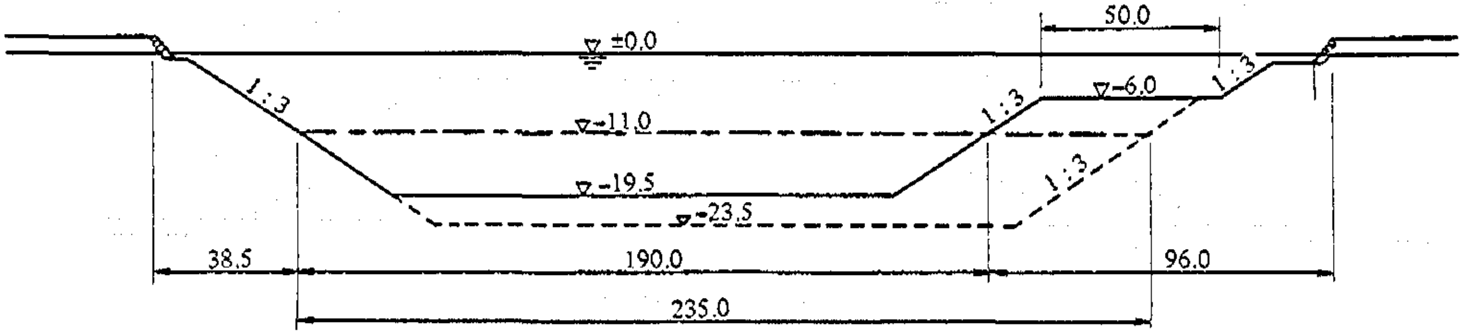
Km 71.964 ~ Km 75.311



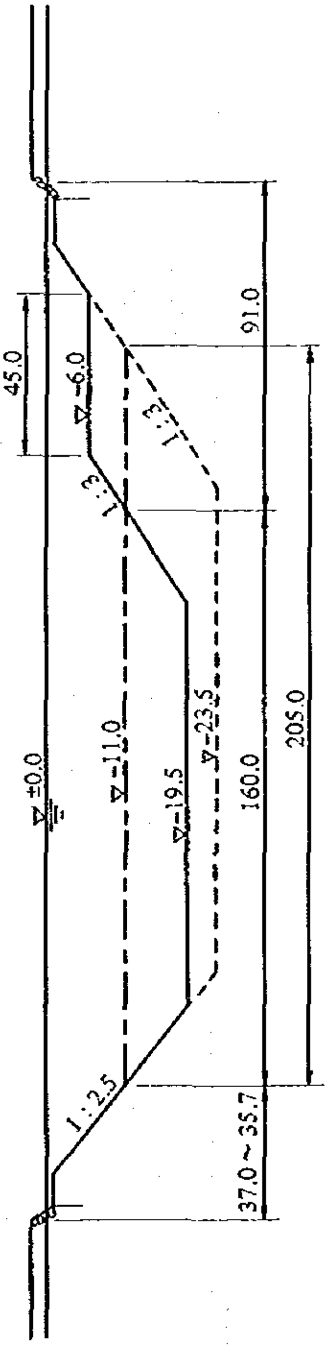
Km 78.400E ~ Km 78.900E



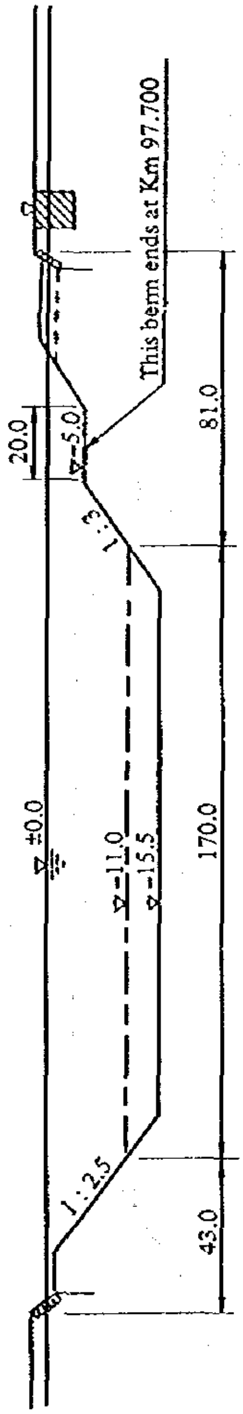
Km 82.576 ~ Km 85.027



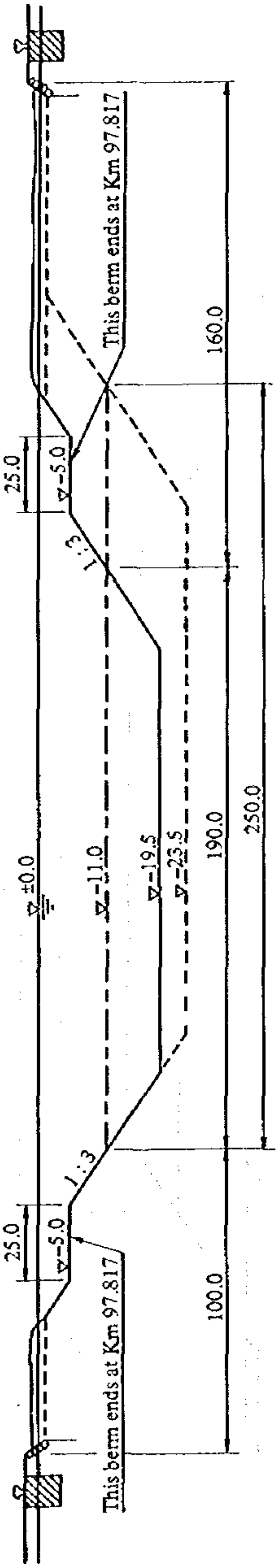
Km 88.814 ~ Km 92.950



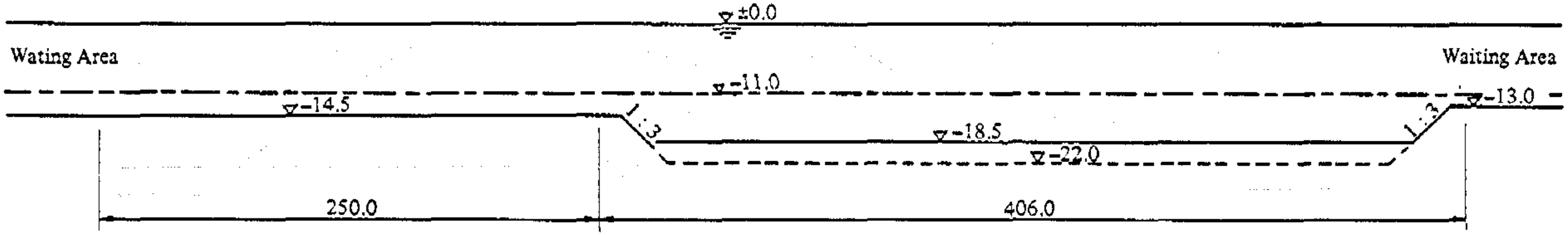
Km 95.418 ~ Km 97.731 (Deversoir West Branch)



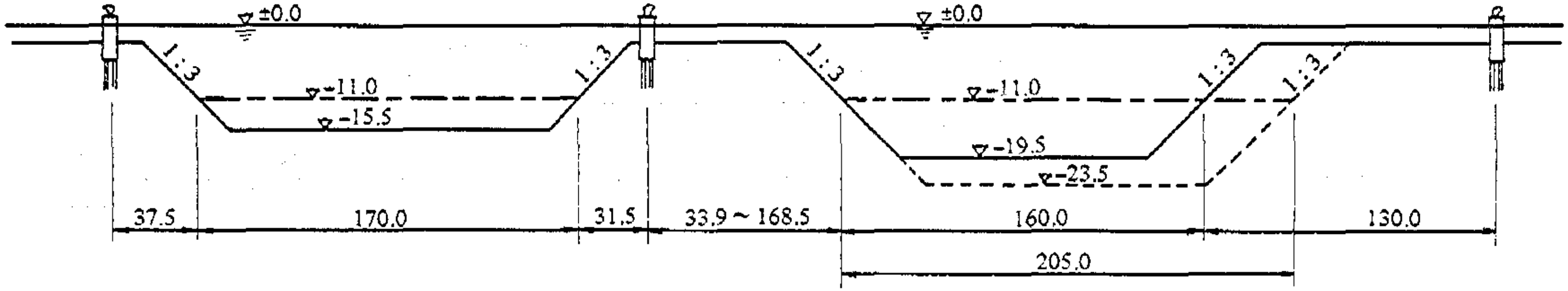
Km 96.000 ~ Km 97.817 (Deversoir East Branch)



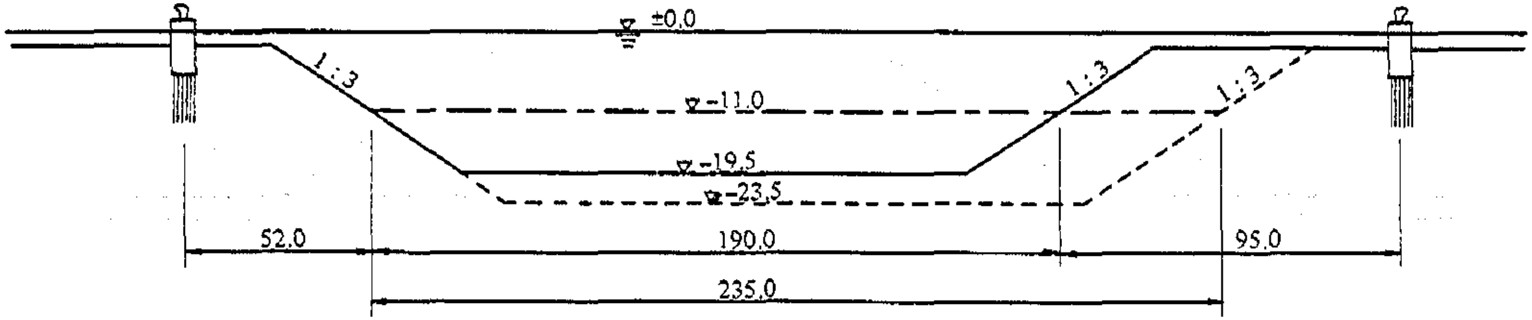
Great Bitter Lake Typical Cross Section Km 110.000



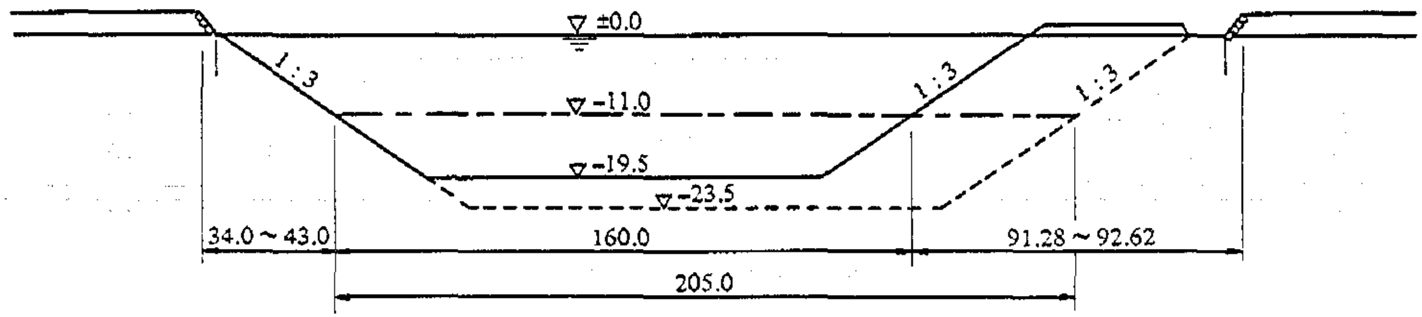
Km 115.570 ~ Km 121.800



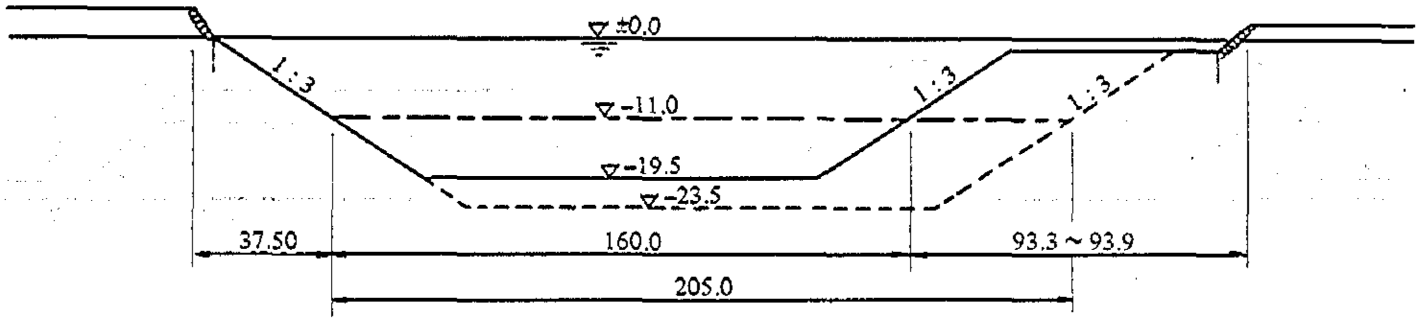
Km 125.507 ~ Km 131.975



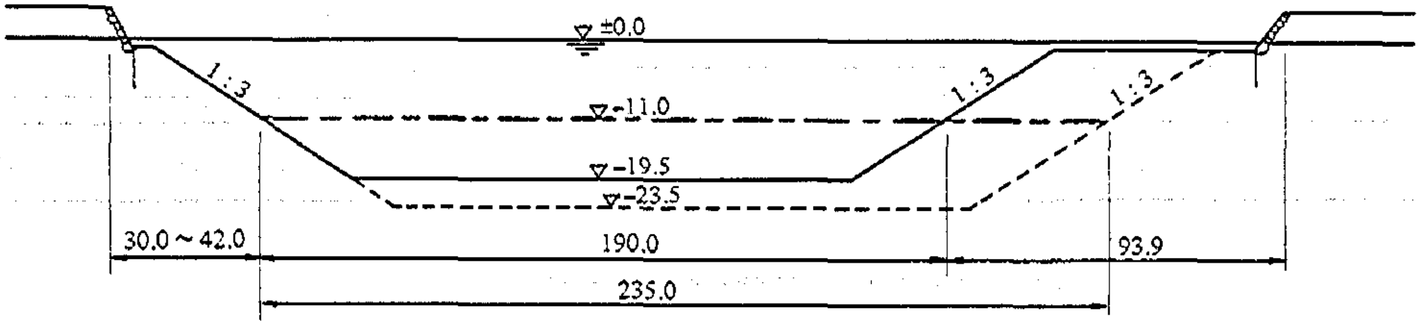
Km 134.544 ~ Km 144.714



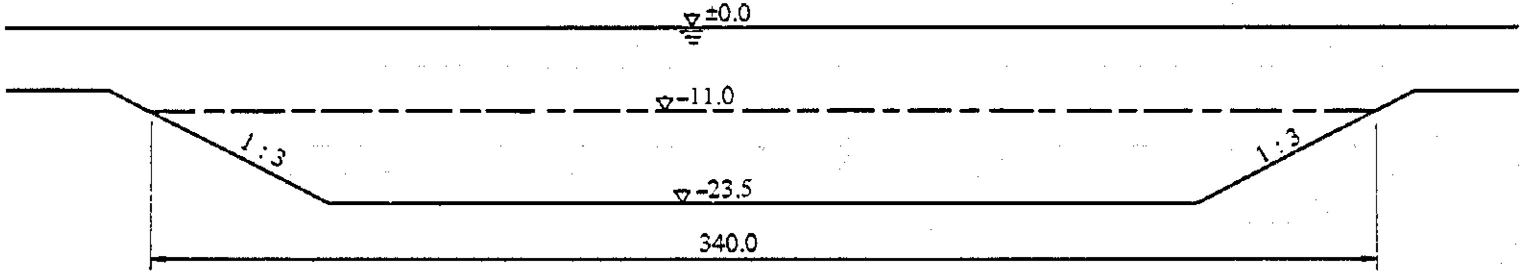
Km 147.146 ~ Km 153.524



Km 154.724 ~ Km 157.550



Hm 3.090 ~ Hm 80.500 (South Entrance)



(2) Natural Conditions

1) Weather

Table V-1-(2)-1 shows the basic conditions of weather at Port Said and Ismailia.

Table V-1-(2)-1 Weather Conditions (1982)

(Unit: Number of Days)

Item \ Months		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Port Said	Fine	19	14	22	18	25	30	31	31	30	28	17	12
	Cloudy	12	14	9	12	5	–	–	–	–	3	13	19
	Rainy	6	15	8	2	3	–	–	–	2	3	7	9
Ismailia	Fine	20	12	23	23	28	30	31	31	29	28	25	18
	Cloudy	11	16	8	7	3	–	–	–	1	3	5	13
	Rainy	7	8	3	1	1	–	–	–	–	2	3	2

2) Visibility

Table V-1-(2)-2 shows the frequency of poor visibility at Port Said, Ismailia, and Suez.

Table V-1-(2)-2 Frequency of Poor Visibility (1981 ~ 1982)

(Unit: %)

Items \ Months		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Port Said	≦ 1 Km	0.6	0.9	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1 ~ 3 Km	1.6	2.2	2.0	0.8	1.6	0.0	0.2	0.2	0.6	0.4	2.1	0.8
Ismailia	≦ 1 Km	0.8	1.3	0.0	1.3	0.0	0.0	0.0	0.2	0.0	0.8	0.4	0.8
	1 ~ 3 Km	3.6	3.6	3.2	2.1	1.0	0.6	1.2	1.8	1.3	2.8	1.5	0.8
Suez	≦ 1 Km	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1 ~ 3 Km	1.0	0.4	0.0	2.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0

3) Wind

Table V-1-(2)-3 shows the frequency of strong winds at the three stations.

Table V-1-(2)-3 Frequency of Strong Winds (1978 ~ 1980)

(Unit: %)

Items	Months	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Port Said	11~21 knots	32.4	43.5	52.4	54.2	50.6	45.6	52.6	44.8	43.8	46.4	40.8	34.5
	≧22 knots	6.1	7.2	9.1	14.9	10.0	4.9	5.2	1.4	1.2	4.1	5.0	3.6
Ismailia	11~21 knots	3.1	4.5	6.5	13.0	11.9	12.6	6.2	1.2	1.6	5.1	3.2	4.5
	≧22 knots	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Suez	11~21 knots	30.2	29.0	38.1	50.6	52.8	58.2	59.1	53.7	65.4	50.4	46.9	21.9
	≧22 knots	0.7	1.0	0.5	3.7	2.8	0.6	0.6	0.2	0.4	0.4	0.4	0.8

4) Tidal Current

Table V-1-(2)-4 shows the frequency of current direction and velocity.

5) Tide

Fig. V-1-(2)-1 shows the variation of the range of astronomical tide throughout the year.

Table V-1-(2)-4 Frequency of Tidal Current Velocity and Direction

Upper: Number of Occurrences
Lower: Percentage of Occurrence

Port Said (St. No. 1)

Direction Velocity	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	SUM
$0.0^m \sim 0.1^m$	30 3.0	29 2.9	101 10.0	81 8.0	46 4.5	36 3.5	18 1.8	50 4.9	37 3.6	24 2.4	120 11.8	108 10.6	16 1.8	24 2.4	23 2.3	27 2.7	772 76.1
$0.1 \sim 0.2$	3 0.3	8 0.8	98 9.7	52 5.1	2 0.2	1 0.1	0 0.0	0 0.0	0 0.0	0 0.0	40 3.9	15 1.5	3 0.3	1 0.1	1 0.1	0 0.0	224 22.1
$0.2 \sim 0.3$	0 0.0	0 0.0	14 1.4	4 0.4	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	1 0.1	0 0.0	0 0.0	0 0.0	0 0.0	19 1.9
SUM	33 3.3	37 3.6	213 21.0	137 13.5	48 4.7	37 3.6	18 1.8	50 4.9	37 3.6	24 2.4	160 15.8	124 12.2	21 2.1	25 2.5	24 2.4	27 2.7	1015 100.0
Average	0.03	0.05	0.11	0.09	0.04	0.04	0.03	0.02	0.02	0.02	0.07	0.06	0.05	0.02	0.02	0.02	0.06

Port Said (St. No. 2)

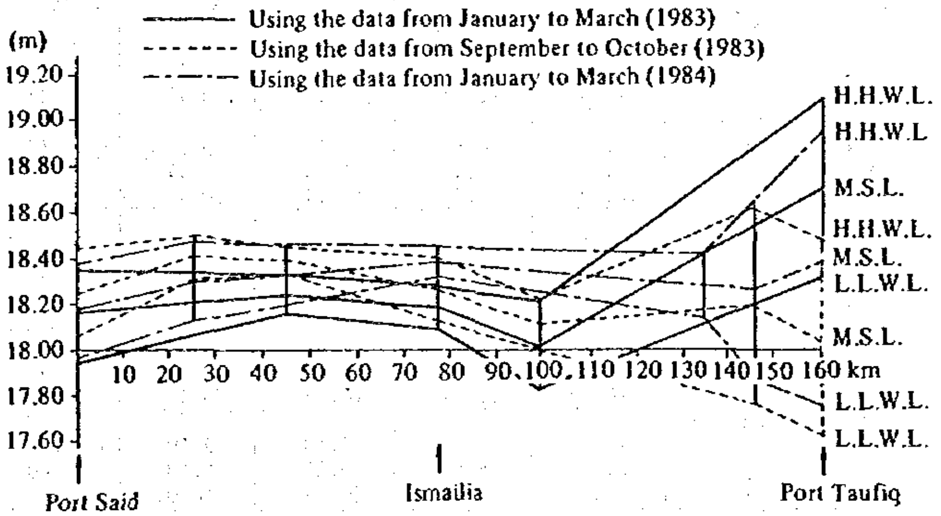
Direction Velocity	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	SUM
0.00^m-0.05^m	7 0.4	12 0.9	12 0.7	5 0.3	4 0.2	2 0.1	12 0.7	7 0.4	15 0.9	32 1.9	73 4.4	50 3.0	44 2.7	54 3.2	33 2.0	5 0.3	370 22.1
0.05-0.10	20 1.2	33 2.0	16 1.0	2 0.1	1 0.1	1 0.1	7 0.4	7 0.4	21 1.2	47 2.8	197 11.8	109 6.5	62 3.7	89 5.3	34 2.0	29 1.7	675 40.3
0.10-0.15	29 1.7	41 2.4	9 0.5	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	8 0.5	71 4.3	196 11.7	81 4.8	47 2.8	78 4.7	36 2.2	33 2.0	629 37.6
SUM	56 3.3	89 5.3	37 2.2	7 0.4	5 0.3	3 0.2	19 1.1	14 0.8	44 2.6	150 9.0	466 27.9	240 14.3	153 9.2	221 13.2	103 6.2	67 4.0	1674 100.0
Average	0.10	0.09	0.07	0.04	0.03	0.04	0.04	0.05	0.07	0.09	0.09	0.08	0.08	0.08	0.08	0.10	0.08

Tousson (St. No. 3)

Direction Velocity	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	SUM
$0.0^m \sim 0.1^m$	55 2.7	13 0.6	14 0.7	15 0.7	8 0.4	7 0.3	42 2.1	176 8.7	107 5.3	22 1.1	20 1.0	19 0.9	17 0.8	28 1.4	55 2.7	65 3.2	663 32.8
$0.1 \sim 0.2$	19 0.9	8 0.4	1 0.0	2 0.1	2 0.1	3 0.1	7 0.3	203 10.0	117 5.8	3 0.1	2 0.1	2 0.1	0 0.0	0 0.0	11 0.5	61 3.0	441 21.8
$0.2 \sim 0.3$	5 0.2	0 0.0	0 0.0	1 0.0	0 0.0	0 0.0	3 0.1	241 11.9	98 4.8	1 0.0	0 0.0	1 0.0	0 0.0	1 0.0	1 0.0	15 0.7	367 18.1
$0.3 \sim 0.4$	0 0.0	0 0.0	0 0.0	0 0.0	1 0.0	0 0.0	0 0.0	167 8.3	38 1.9	2 0.1	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	1 0.0	209 10.3
$0.4 \sim 0.5$	0 0.0	0 0.0	1 0.0	0 0.0	0 0.0	0 0.0	0 0.0	170 8.4	7 0.3	0 0.0	0 0.0	1 0.0	0 0.0	0 0.0	0 0.0	0 0.0	179 8.8
$0.5 \sim 0.6$	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	92 4.5	5 0.2	0 0.0	1 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	98 4.8
$0.6 \sim 0.7$	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	46 2.3	8 0.4	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	54 2.7
$0.7 \sim 0.8$	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	6 0.3	4 0.2	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	10 0.5
$0.8 \sim 0.9$	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	1 0.0	1 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	2 0.1
SUM	79 3.9	21 1.0	16 0.8	18 0.9	11 0.5	10 0.5	52 2.6	1102 54.5	385 19.0	28 1.4	23 1.1	23 1.1	17 0.8	29 1.4	67 3.3	142 7.0	2023 100.0
Average	0.07	0.07	0.07	0.06	0.06	0.07	0.07	0.29	0.19	0.08	0.07	0.07	0.03	0.04	0.06	0.11	0.22

Port Taufiq (St. No. 4)

Direction / Velocity	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	SUM
$0.0^{m} \sim 0.1^{m}$	3 0.1	15 0.6	73 3.2	29 1.3	15 0.6	5 0.2	23 1.0	18 0.8	21 0.9	34 1.5	77 3.3	14 0.6	4 0.2	0 0.0	5 0.2	4 0.2	340 14.7
0.1 ∿ 0.2	0 0.0	1 0.0	86 3.7	2 0.1	1 0.0	0 0.0	0 0.0	0 0.0	0 0.0	3 0.1	126 5.5	3 0.1	0 0.0	0 0.0	0 0.0	0 0.0	222 9.6
0.2 ∿ 0.3	0 0.0	0 0.0	100 4.3	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	123 5.3	0 0.0	1 0.0	0 0.0	0 0.0	0 0.0	224 9.7
0.3 ∿ 0.4	0 0.0	0 0.0	129 5.6	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	109 4.7	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	238 10.3
0.4 ∿ 0.5	0 0.0	0 0.0	119 5.1	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	144 6.2	1 0.0	0 0.0	0 0.0	0 0.0	0 0.0	264 11.4
0.5 ∿ 0.6	0 0.0	0 0.0	162 7.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	224 9.7	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	386 16.7
0.6 ∿ 0.7	0 0.0	0 0.0	146 6.3	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	139 6.0	1 0.0	0 0.0	0 0.0	0 0.0	0 0.0	286 12.4
0.7 ∿ 0.8	0 0.0	0 0.0	142 6.1	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	1 0.0	85 3.7	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	228 9.9
0.8 ∿ 0.9	0 0.0	0 0.0	39 1.7	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	55 2.4	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	94 4.1
0.9 ∿ 1.0	0 0.0	0 0.0	14 0.6	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	11 0.5	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	25 1.1
1.0 ∿ 1.1	0 0.0	0 0.0	4 0.2	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	4 0.2
SUM	3 0.1	16 0.7	1014 43.9	31 1.3	16 0.7	5 0.2	23 1.0	18 0.8	21 0.9	38 1.6	1093 47.3	19 0.8	5 0.2	0 0.0	5 0.2	4 0.2	2311 100.0
Average	0.03	0.04	0.48	0.05	0.04	0.02	0.02	0.02	0.03	0.07	0.45	0.11	0.08	0.0	0.02	0.02	0.43



Note: H.H.W.L. = MSL + (M_2 S_2 + K_1 + O_1)
L.L.W.L. = MSL - (M_2 +S_2 + K_1 + O_1)

Fig. V-1-(2)-1 Tidal Range along the Canal

6) Waves

Table V-1-(2)-5 shows the frequency of Wave direction and wave height at Port Said and Suez.

Table V-1-(2)-5 Frequency of Wave Direction and Wave Height

Port Said

Upper: Number of Occurrence
Lower: Percentage of Occurrence

Direction / Height	260∿280°	290∿310°	320∿340°	350∿10°	20∿40°	50∿70°	Total
≤0.75^m	279 (4.0)	528 (7.2)	533 (7.2)	267 (3.6)	151 (2.1)	118 (1.6)	1,876 (25.5)
1∿1.5^m	590 (8.0)	1,272 (17.3)	1,318 (17.9)	496 (6.7)	205 (2.9)	155 (2.1)	4,036 (54.8)
2∿2.5^m	200 (2.7)	371 (5.0)	398 (5.4)	117 (1.6)	29 (0.4)	25 (0.3)	1,140 (15.5)
3∿3.5^m	41 (0.6)	60 (0.8)	78 (1.1)	24 (0.3)	1 (0.0)	3 (0.0)	207 (2.8)
4∿5.5^m	13 (0.2)	37 (0.5)	29 (0.4)	8 (0.1)			87 (1.2)
6∿7.5^m	1 (0.0)	8 (0.1)	6 (0.1)				15 (0.2)
Total	1,124 (15.3)	2,276 (30.9)	2,362 (32.1)	912 (12.4)	386 (5.2)	301 (4.1)	7,361 (100.0)

Upper: Wave Height (m)
Middle: Wave Period (sec)
Lower: Percentage of Occurrence

Direction / Fetch Length / Wind Velocity (knot)	105°∿135°	135°∿164°	165°∿194°	195°∿224°	225°∿254°
	33.05 Km	52.09 Km	59.46 Km	48.62 Km	20.52 Km
x1.4 2 (1∿3)	0.05 1.05 (1.4)	0.06 1.10 (0.9)	0.06 1.11 (0.7)	0.06 1.09 (0.3)	0.05 1.00 (0.3)
x1.4 5 (4∿6)	0.25 2.06 (1.4)	0.27 2.21 (1.0)	0.28 2.26 (0.7)	0.27 2.19 (0.2)	0.22 1.89 (0.2)
x1.4 8.5 (7∿10)	0.54 2.86 (0.4)	0.61 3.13 (1.2)	0.64 3.21 (1.1)	0.60 3.01 (0.4)	0.46 2.59 (0.3)
x1.4 13.5 (11∿16)	0.99 3.71 (0.1)	1.17 4.11 (1.4)	1.22 4.23 (1.8)	1.14 4.05 (0.4)	0.83 3.31 (0.4)
x1.4 19.0 (17∿21)	1.52 4.42 (0.0)	1.81 4.94 (0.1)	1.90 5.10 (0.7)	1.76 5.86 (0.1)	1.25 3.91 (0.1)
x1.4 24.5 (22 ∿)	2.05 5.00 (0.0)	2.47 5.62 (0.0)	2.60 5.81 (0.1)	2.40 5.53 (0.0)	1.68 4.40 (0.1)

7) Sedimentation

The primary conditions concerning sediment are shown by the results of the littoral drift simulation at Port Said (See Fig. II-2-(9)-1).

(3) Traffic Flow

1) General Trends in World Maritime Trade

The oil demand registered a decrease for 4 consecutive years after the second Oil Crisis. It finally hit rock bottom in 1983 and started to show a rebound in the free world together with the global economic recovery and growth.

But its tempo is very slow with a small growth rate of 1% per annum, and an expectation of a big jump is in no way legitimate.

On the other hand, taking a look at the suppliers' side of the oil market, there are, two distinct factors. First, the OPEC nations have changed their role from "base suppliers" to "buffer suppliers" in the oil market since the second Oil Crisis. Second, the utilization of alternative energy sources has slowed the growth of demand for oil.

Nethertheless in the long run, the OPEC producers will again assume an important role with their large reserve in output capacity, while the supply capacity of the non-OPEC producers is expected to reach its limit in and after 1990.

With such a background, although the seaborne trade volume for oil increased after it reached the bottom in 1983, no marked growth is immediately foreseeable. Due to such factors as the glut market in the industrialized countries, increasing domestic demand among the oil producing countries and the expansion of the pipeline network, the seaborne trade volume for oil will not increase in the near future.

Which means, as Table V-1-(3)-1 indicates, that an average annual growth rate of only 1.2% or so is a reasonable estimate. Thus we project 1.36 billion tons in 1985, 1.45 billion tons in 1990, 1.5 billion tons in 1995 and 1.58 billion tons in 2000.

For dry cargo, the following estimates are given.

(i) Iron Ore

The seaborne trade for iron ore will be 297 million tons in 1985, 316 million tons in 1990, 349 million tons in 1995 and 388 million tons in 2000.

The average annual growth from 1983 to 1995 is expected to be 2.2%.

(ii) Coal

The seaborne trade for coal will grow from the 1983 level of 208 millions tons to 243 million tons in 1985, 307 million tons in 1990, 361 million tons in 1995 and 454 million tons in 2000.

4.7% is expected as the average annual growth rate.

(iii) Cereals

The seaborne trade for cereals will be 195 million tons in 1983, 217 million tons in 1985, 239 million tons in 1990, 271 million tons in 1995 and 297 million tons in 2000.

During this period, the average annual growth rate is estimated to be 2.8%.

(iv) Other Dry Cargoes

The seaborne trade of phosphate will increase from 40 million tons in 1982 to 66 million tons in 2000 while the bauxite alumina trade will increase from 38 million tons in 1982 to 42 million tons in 200.

Other dry cargoes will show an increase from the 1982 level of 1,162 million tons to

2,439 million tons in 2000.

Thus, the total seaborne trade volume up to the year 2000 is forecasted as shown in Table V-1-(3)-1.

Table V-1-(3)-1 Forecast of Seaborne Trade Volume by Commodity

(1,000,000 M/T)

Commodities	1979	1980	1981	1982	1983	1985	1990	1995	2000	Annual Average Growth Rate (%) 1983 ~ 2000
Oil and Oil Products	1,817	1,638	1,482	1,328	1,292	1,360	1,450	1,500	1,582	1.2
Iron Ore	327	314	303	273	268	297	316	349	388	2.2
Coal	159	188	210	209	208	243	307	361	454	4.7
Cereals	182	198	206	200	195	217	239	271	297	2.8
Phosphate	48	48	42	40	46	48	53	59	66	2.16
Bauxite Alumina	46	48	45	38	42	42	42	42	42	0
Others	1,176	1,214	1,218	1,162	1,132	1,352	1,698	2,131	2,439	4.62

Fearnleys Report
JMRI Report

2) Future Transits via the Suez Canal

(i) The following is a summary of the future trend of aggregate maritime trade in the years 1990 and 2000 as shown above.

(1,000,000 M/T)

Year / Cargo	1983	1990	2000
Oil and Oil Products	1,292	1,450	1,582
Dry Cargo	1,891	2,655	3,686
Total	3,183	4,105	5,268

As we estimate the future cargo volume via the Suez Canal, we make an assumption that the cargo volumes via the Suez Canal as opposed to the aggregate orldwide seaborne trade in 1990 an 2000 will be 8.5% and 9% respectively as based on the recent data shown above in Table II-3-(2)-2.

On this basis, the potential cargo volumes via the Canal in 1990 and 2000 will come in the range calculated below.

In 1990 $(1,450 + 2,655) \times 0.085 = 348.9$ million M/T
In 2000 $(1,582 + 3,686) \times 0.09 = 474.1$ million M/T

Then assuming the composition rates of the cargoes via the Canal based on the data taken from above Table as 35% for tanker cargo and 65% for dry cargo for 1990, 30% for tanker cargo and 70% for dry cargo for 2000, we calculate the cargo transit volumes via the Canal for 1990 and 2000.

The resulting figures are as follows:

(1,000,000 M/T)

Cargo Year	Tanker Cargo	Dry Cargo	Total
1990	122	227	349
2000	142	332	474

To tabulate the required loading capacity to meet the cargo volume, we first establish a coefficient by comparing the commodity transit volume via the Canal based on the SCA data in and after 1977 with the vessel-type (tanker or non-tanker distribution) traffic data (SCNT). The results are as shown in Table V-1-(3)-2.

Table V-1-(3)-2 Coefficient of Vessel Volume to Cargo Volume

Item Year	Tanker Volume 1,000 DWT		Tanker Cargo 1,000 M/T	Non-Tanker Volume 1,000 DWT		Non-Tanker Cargo 1,000 M/T
1977	151,136	4.32	34,945	208 669	2.23	93,748
1978	147,848	4.46	33,179	251,044	2.51	116,600
1979	172,556	4.76	36,254	259,046	2.08	124,395
1980	178,176	4.20	42,468	277,106	2.07	133,808
1981	274,004	5.00	54,777	298,356	2.11	141,651
1982	267,272	3.20	83,451	331,031	2.24	147,942
1983	273,018	2.78	98,233	348,126	2.20	158,472

Note: (1) The dead-weight tonnage of the tankers for 1977~1979 is taken by multiplying the SCNT by 2.0, the conversion coefficient.

(2) The dead-weight tonnage of the non-tankers is taken by multiplying the SCNT by 1.44, the actual average conversion coefficient.

Thus, this coefficient indicates the indexes to show how much loading capacity (DWT) is required to transport a unit of 1 M/T of the cargo via the Canal.

According to recent figures, non-tankers, that is dry cargo, have shown an average coefficient of 2.15 while tanker cargo reached a peak at 5.0 and after the First Stage Development Project of the Canal it decreased to 2.8 in 1983.

This means that as a result of the extension work, super-tankers are now able to use the Canal, and the number of the unloaded northbound vessels (including partially loaded vessels) has decreased.

Following are the expected required loading capacity in 1990 and 2000 (forecasted volumes of transit vessels) based on the prospective cargo volumes via the Canal. The coefficient of 4.0 for tanker cargo and 2.15 for the non-tankers which stand as average figures for recent performance are applied.

Tankers: (Estimated Cargo Volume) x (Coefficient)
= (Forecasted Loading Capacity in Transits in million DWT)

In 1990: 122 x 4.0 = 488

In 2000: 142 x 4.0 = 568

Non-Tankers: (Estimated Cargo Volume) x (Coefficient)
= (Forecasted Loading Capacity in million DWT)

In 1990: 227 x 2.15 = 488

In 2000: 332 x 2.15 = 714

Now, if we make a table from these figures, we get the following data as the forecasted necessary loading capacities for 1990 and 2000.

(1,000,000 DWT)

	Tankers	Non-Tankers	Total
1990	488	488	976
2000	568	714	1,282

Naturally, these forecasted figures are based on the assumption that the current conditions of the Canal itself and other external conditions remain the same as at present.

Therefore, if any change occurs in the capacity of the Canal, the commodities and vessels in transit will change along with it.

As we presume that although some bulk carriers may move towards a larger size as seen in the current trend, they will not repeat a move to ultra-super size tankers.

On the other hand, the position and demand for VLCC among the tankers may be stronger but will certainly not be weaker than at present.

If subsequent extension work enables VLCC's to use the Canal with a full-load, a remarkable change in transit patterns may appear.

The forecast number of transit vessels via the Suez Canal is calculated according to to the procedure described below.

(ii) The average size of the transit vessels in 1979 ~ 1983 is obtained as described below based on Table V-1-(3)-2 of the report as well as on the values given in the SCA report.

Year	Total Transit Vessels Volume	Number	Average Size
1979	431,602,000 DWT	20,363	21,195 DWT
1980	455,282,000	20,795	21,894
1981	572,360,000	21,577	26,526
1982	598,303,000	22,545	26,538
1983	621,144,000	22,224	27,949

The future changes in average vessel size can be forecast on the basis of the trend of the past changes indicated by these figures. That is, the annual growth (DWT) of the average size of the transit vessels during the period from 1979 to 1983 is obtained in the following expression.

(27,949 − 21,159) ÷ 4 = 1,688.5 ≒ 1,690 (DWT)

If this growth trend in the average vessel size is also assumed for the future, then the average vessel size in 1990 and 2000 can be calculated as described below.

1990: 27,949 + (1,690 × 7) = 39,779 (DWT)
2000: 39,779 + (1,690 × 10) = 56,679 (DWT)

In practice, however, it seems unlikely that the average vessel size will continuously increase at this rate up to 1990 ~ 2000. Thus assumption were made that the actual average vessel size will be 90% in 1990 and 80% in 2000 of the values obtained above.

Then we have:
1990: 35,801 (DWT)
2000: 45,343 (DWT)

Now, we can estimate the number of the transit vessels in 1990 and 2000 by dividing the forecast transit vessels volume by these average vessel sizes. Then we have:

1990: 976 (× 10^5) ÷ 35,801 = 27,262
2000: 1,282 (× 10^6) ÷ 45,343 = 28,273

Thus, it is expected that the number of the Canal transit vessels will be approximately 27,000 in 1990 and 28,000 in 2000. That is, the number of transit vessels per day will be 75 and 77, respectively.

(4) Navigational Conditions

1) Traffic Conditions

(i) Transit System

For vessels transiting the Canal, the convoy transit system involving two southbound convoys and one northbound convoy a day as shown in Fig. V-1-(4)-1 is presently employed. This transit system will remain unchanged as a rule even after completion of the Second Stage Development Project of the Canal.

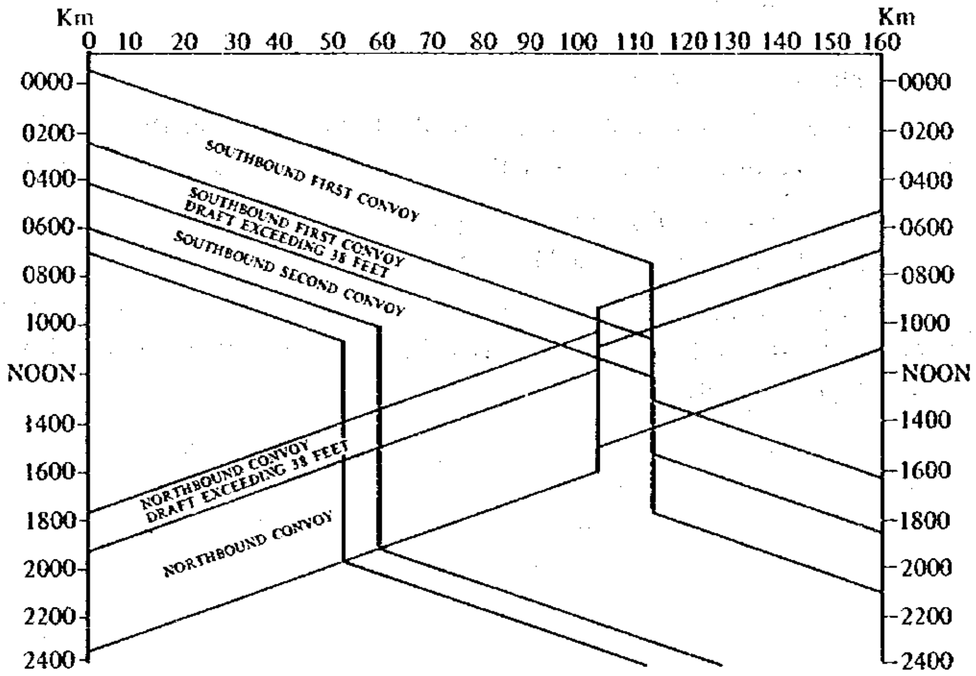


Fig. V-1-(4)-1 Traffic Diagram

(ii) Transit Route

i) 1st Southbound Convoy

Vessels with draft not exceeding 38' depart from the water within the port and pass through the west channel; those with draft exceeding 38' depart from the water outside the port and pass through the East Channel, and head to Suez via the Ballah East Branch, Timsah East Branch, Deversoir West Channel, Great Bitter Lake Western Anchorage anchor and Kabrit West Branch.

ii) 2nd Southbound Convoy

Vessels depart from the water within Port Said harbour and pass through the West Channel, are tied up at the Ballah West Branch or anchor in the Timsah Lake anchorage, then head to Suez via the Kabrit West Branch.

iii) Northbound Convoy

VLCCs etc. from the outer waiting anchorage, and others from the Inner Waiting Anchorage proceed through the Kabrit East Channel and either anchor in the Great

Bitter Lake Eastern Anchorage or pass through there. Then those calling at the port of Port Said head to the Port Said West Channel whereas others head to the East Channel via the Deversoir East Channel and Ballah East Channel.

Note, however, that after the completion of the waiting buoy berth now under construction in the Port Said West Channel, all vessels of the northbound convoy will proceed to the Mediterranean Sea via the East Channel.

(iii) Priority Order in Organizing Convoys

The priority given for vessels of the 1st southbound convoy during their passage between Port Said and Great Bitter Lake is, in descending order, vessels with draft not exceeding 38', vessels with draft exceeding 38', and then 3rd generation containerships. The priority during their passage between the Great Bitter Lake and Suez is, in descending order, 3rd generation containerships, VLCCs, and then vessels with draft not exceeding 38'.

No specific priority order is established for vessels of the 2nd southbound convoy.

The priority given to vessels of the northbound convoy is, in descending order, 3rd generation containerships, loaded VLCCs, liquefied gas carriers, conventional tankers, and then vessels of other types.

(iv) Maximum Draft

The maximum drafts are 53 ft for northbound vessels and 42 ft for southbound vessels.

Note, however, that by taking a course through the east channel, arrangement can be made to transit vessels with a draught of more than 42 ft.

After the completion of the 2nd construction phase of the Canal, the water depth will become 23.5 m. Thus fully loaded 270,000 DWT and ballasted 500,000 DWT tankers in the northbound convoy will become transitable. However, the maximum draft for the southbound vessels of 42 ft will remain unchanged as a rule even after completion of the Second Stage Development Project.

(v) Transit Speed

The Rules of Navigation determine the transit speed as below:

1st/2nd southbound convoys	14 km/h
Northbound convoy	
Loaded VLCCs, etc.	13 km/h
Other vessels	14 km/h

Note, however, that the mean statistical speeds during the one-month period in August, 1983 were as follows:

Southbound vessels	15.6 km/h
Northbound vessels	16.1 km/h

(vi) Ship-to-Ship Distance

The SCA establishes standards for distance between ships as tabulated in Table V-1-(4)-1.

The average statistical figures during the one-month period in August, 1983 were as given in Table V-1-(4)-2.

Table V-1-(4)-1 Time Interval between Vessels

Dead Weight Tons	Minimum Time Intervals in Minutes
Up to 30,000	6
30,000 to 60,000	10
60,000 to 140,000	16
140,000 to 250,000	20
Larger than 250,000	25
VLCC in ballast	16

Table V-1-(4)-2 Average Time Interval for One Month in August, 1983

(Minutes)

Kind of Vessel \ Direction		Northbound		Southbound	
		P. Said	Suez	P. Said	Suez
Container		9.56	9.45	12.50	8.85
Tanker	Less than 60,000 G.T.	16.95	13.88	13.82	8.95
	60,000 G.T and more	21.89	17.96	19.53	10.80
Others		10.15	9.07	11.44	8.85

(vii) Pilots

Employment of pilots for vessels of 300 SCGT or more is compulsory. For vessels of 80,000 SCGT or more and third generation container vessels etc., an extra pilot is normally arranged.

(viii) Escort Tugs

An escort tug, or tugs are arranged as follows: One for loaded vessels of 110,000 to 150,000 DWT and ballasted vessels of 200,000 DWT or more, and two for loaded vessels of 150,000 DWT or upwards as the situation demands.

2) Traffic Controls

(i) Traffic Diagram

Traffic controls are carried out by exchanging traffic information through VHF and UHF radiotelephony among the Harbour Offices in Port Said and Suez, each signal station, each pilot and Head Office in Ismailia with traffic diagrams prepared.

(ii) SCVTMS

The Suez Canal Vessel Traffic Management System consists of tracking radars, a Loran-C position-fixing chain, a computer network and a communication network. The SCVTMS is a superb, centralized vessel traffic control system capable of issuing alarms on detecting abnormalities in ships' speeds, off-track, and ship-to-ship distances. However, this system is still in its testing and training stages at present.

It is anticipated that the SCVTMS will demonstrate its sophisticated centralized vessel traffic control services in the future.

3) Anchoring and Berthing Conditions

(i) Anchoring Conditions

Twenty-three waiting anchorages are provided in Port Said, 5 in Lake Timsah, 60 in the Great Bitter Lake, and 77 in Suez.

On the most congested day of 1982, 38 northbound vessels and 39 southbound vessels transited through the Canal in one day, but no difficulties whatsoever were experienced.

(ii) Berthing Conditions

Within the port of Port Said, 30 waiting buoy berths are provided.

In the future, the new buoy berths now under construction in the south part of the West Branch will come into service in place of the waiting buoy berths in the port.

The Ballah West Branch is now used for tying up vessels of the 2nd southbound convoy, and it can accommodate 15 vessels.

4) Arrival and Waiting Conditions

Figs. V-1-(4)-2 and 3 show the distributions of arrival time and waiting period of transiting vessels in Port Said and Suez in the period from September 12, 1983 to October 2 of the same year.

As for arrival time, southbound vessels had their peak during the period from 1400 to 1800 hours, right before the closing time of reception for the 1st convoy. Other times show relatively flat distribution without any distinct peaks or troughs. Northbound vessels had their peak during the period from 1200 to 1400 hours and trough during the period from 0400 to 0600 hours, but other times show a relatively flat distribution.

As for waiting hours, there are peaks in the case of 12 to 14 hours at Suez, and in the case of 14 to 18 hours at Port Said.

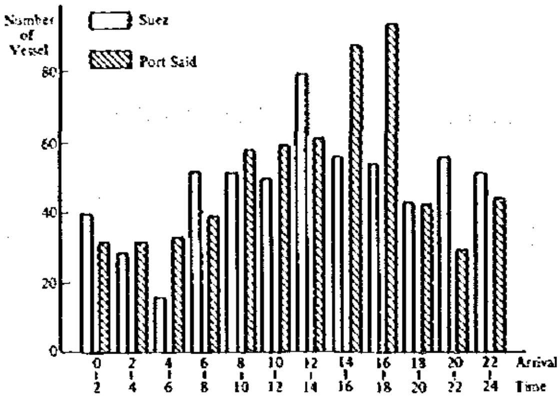


Fig. V-1-(4)-2 Distribution of Arrival Time

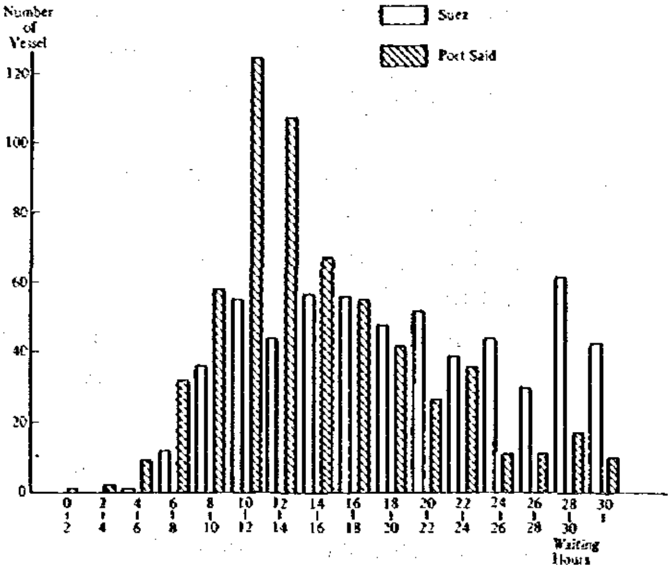


Fig. V-1-(4)-3 Distribution of Waiting Hours

5) Manoeuvrability

(i) Stopping Distance in the Canal

Table V-1-(4)-3 is the summary of the data of the stopping trials carried out in the Canal by SCA, and Fig. V-1-(4)-4 shows the records of reverse stopping distances presented by the Japan Dockmasters' Association.

Table V-1-(4)-3 Summary of Stopping Trials in the Canal

Trial No.	1	2	3	4	5	Average
Stopping Distance	1,069	575	1,260	975	1,255	1,026.8
Stopping Time	9m27s	7m13s	12m45s	11m12s	11m26s	10m24.6s
Current	0.5 m astern	11.0 m ahead	0.6 m astern	11.0 m ahead	0.5 m astern	
Wind	24 kt 15 dgs	nil	14 kt 360 dgs	nil	21 kt 15 dgs	
Initial Speed	6.98 kt	5.68 kt	6.78 kt	5.03 kt	7.01 kt	6.296 kt
No. of Tugs	2	2	2	1	1	

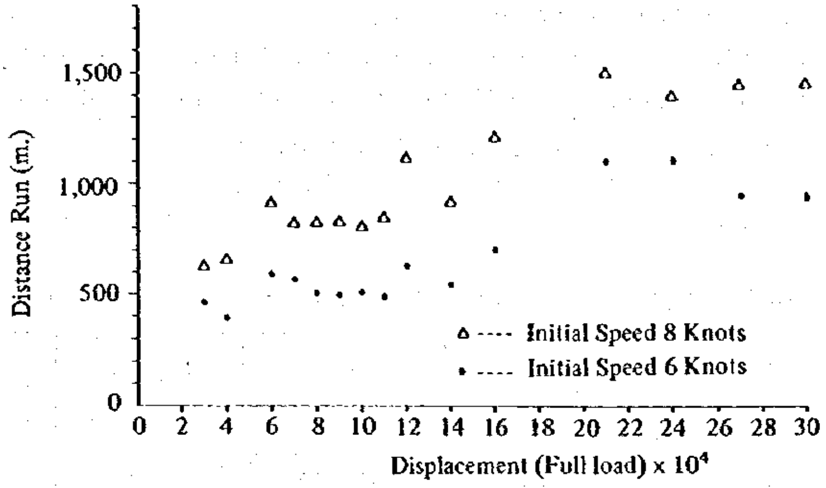


Fig. V-1-(4)-4 Reverse Stopping Distance

(Source: Japan Dockmasters' Association)

(ii) Qualification and Training of Canal Pilots

Table V-1-(4)-4 shows the age limits, qualifications, training, experience and other requirements for being Canal pilots.

i) For training reliable pilots, an age limit should be determined.

ii) The training period should be extended with training curricula upgraded. Employment of the simulator training programme should be considered.

iii) The physical fitness of trainees should be checked regularly.

iv) A special training programme for coping with emergency situations should be implemented.

Table V-1-(4)-4 Qualifications, Training and Other Requirements to become Pilots

Age Limit for Certification	Certificate of Competency Necessary to become a Pilot	Sea-going Experience
None	Master of ocean-going vessel	Nil

Training and Examination	Rank	Renewal	Age Limit for Service
2-month long training with the qualification of harbour pilot, thence examination is to be taken.	4	Nil	60 (Extended service beyond the age limit is possible under special contract.)

(iii) Experience and Age Distributions of Canal Pilots

Table V-1-(4)-5 gives the experience and age distributions of Canal Pilots as of September, 1983.

Although the age limit of 60 is considered appropriate, regular physical fitness checks should be carried out. This is especially important considering the contract system available for pilots exceeding the limit of 60 years of age.

Further, it is also considered to be problematic that those pilots with experience not exceeding 5 years comprise about 50% of the total number of Canal Pilots.

(iv) Salvage, Escort and Harbour Tugs and Pilot Boats

Table V-1-(4)-6 is a list of salvage boats, escort tugs, harbour tugs, and pilot boats owned by the SCA.

Table V-1-(4)-5 Distribution of Careers and Age of Canal Pilots

Kind of Pilot	Career Length	Age	Number	Remarks
Pilot	Less than 5 years	30 ~ 40	120	
Major Pilot	More than 5 years	35 ~ 39	24	
		40 ~ 44	14	
	Less than 10 years	45 ~ 49	7	
		50 ~ 59	0	
		Over 60	1	Contracted
Distinguished	More than 10 years	45 ~ 49	15	
		50 ~ 54	17	
	Less than 15 years	55 ~ 59	16	
		Over 60	2	Contracted
Chief Pilot	More than 15 years	50 ~ 54	6	
		55 ~ 59	29	
		Over 60	13	Contracted
Total			264	

Table V-1-(4)-6 Salvage, Escort, Harbour Tugs and Pilot Boats

	Port Said			Ismailia			Suez		
	HP	Speed	No.	HP	Speed	No.	HP	Speed	No.
Salvage Tug	4,500	15	1	6,400	15	1	6,400	15	1
Escort Tug	3,200	13	2	3,200	13	2	3,200	13	2
	3,700	13	1	3,700	13	4	3,700	13	3
	3,400	13	2						
Harbour Tug	2,600	13	2	3,700	13	2	1,600	11.5	2
	1,600	12	6	1,600	12	3			
Pilot Boat	300	13	8	300	13	6	300	13	12
	390	15	1	390	15	7	400	15	6
	740	14	1	740	14	2	740	14	3
	1,300	25	2	1,300	25	2	650	22	4
	650	22	6				1,300	25	3
							350	13	2
Total			32			29			38

6) Aids to Navigation

Table V-1-(4)-7 compares the rates of installation of aids to navigation of the Suez Canal with those of other canals, channels and traffic routes in rivers.

The number of aids to navigation per km in the Canal is considered to be satisfactory in comparison with other waterways. Note, however, that in the approach areas of Port Said and Suez, some sort of reinforcement or improvement is considered necessary, as many of the respondents of the questionnaire survey have suggested.

Also, as for the maintenance of the aids to navigation, improved maintenance, particularly for those located in the approaches, is necessary. Many of the respondents to the questionnaire survey requested improved maintenance of the aids to navigation located in the approach areas. Strong proposals for the improved maintenance of the aids to navigation are also enunciated in the section on Urgentry-needed countermeasures.

Table V-1-(4)-7 Comparison of Number per Kilometer and Interval of Aids to Navigation

Name of Waterway	Number of Aids to Navigation per Km	Mean Distance between Aids to Navigation (m)
Suez Canal	2.71	738
Maas River	3.40	588
North Sea Canal	3.30	606
Elbe River	2.15	932
Kiel Canal	1.09	1,833
Kanmon Strait	2.72	735
Panama Canal	3.40	588
Average	2.48	805

7) Survey of Canal Users

(i) Answers from Master of Transit Vessels

i) As for the areas where risk of danger was felt, Port Said and Suez were frequently mentioned.

ii) The type of danger felt during transit were grounding 70% followed by collision 30%.

iii) As for the causes of grounding, the respondents most frequently cited improper aids to navigation.

iv) No specific trend was noted concerning the direction of transit (whether it is northbound or southbound), vessel size, and vessel type.

v) Many comments were made about the need for racon, and the lack of information and communication.

(ii) Answers from Canal Pilots

Among the few answers which were received from the Canal Pilots, requests for improving the aids to navigation were found.

(iii) Answers from Japanese Captains

i) The overwhelmingly large portion of these answers stressed that the areas which they felt most dangerous are Port Said and Suez.

ii) The types of danger felt during transit was collision with vessels and others 59% followed by grounding 41%.

iii) The notable causes of collision stated were narrow water, complexities of meeting, and improper aids to navigation, whereas the notable causes of grounding mentioned were narrow water, strong current and improper aids to navigation.

iv) Many comments were found related to requests for improving communications, widening of anchorage, and picking up of pilots at waiting areas.

8) Analysis of Accident Records

(i) SCA's Accident Records

i) Annual Changes in Risk Levels

The risk levels have decreased by 59% since the completion of the 1st phase of widening/deepening construction.

ii) Monthly Changes in Risk Levels

The occurrence of accidents in the Canal is closely connected to the seasonal sandstorms. Although this relationship was evident during the period before the First Stage Development Project, it fell slightly in the post-construction period.

Concerning Port Said, the correlation with season of the year is not significant at all.

iii) Changes in Risk Levels by Location

If we compare risk levels by location before and after the completion of the First Stage Development Project of the Suez Canal, it is noteworthy that risk levels in Port Said after completion are 94%, and those in Suez are 85% of pre-project levels, respectively, thus showing little change from the pre-construction work period.

In the Great Bitter Lake, the risk level after completion of the project is 66%, which also shows only a slight decrease.

In the waters of the Canal other than the ports and lakes, the post-construction work risk levels were reduced to 30 to 40% on the whole.

This decrease of the risk level is due to the widening and the deepening of the Canal, the completion of the execution, and also to the improvement of the navigation aids and the mooring operations.

iv) Assessment of Risk Levels by Direction of Transit and by Time of the Day

In the pre-construction work period, the occurrence of accidents in southbound vessels at El Ballah and El Kabrit, and in northbound vessels at El Kabrit were significant.

In the post-construction work period, the occurrence of accidents in southbound vessels at El Ballah, and in northbound vessels at El Kabrit were distinct.

There is not much relation between the risk levels and time of the day (whether it was daytime or nighttime).

(ii) Accident Records in Preliminary Study Team format

i) Causes of Accidents

Unskilled ship manoeuvring techniques	15%
Erroneous engine operation	14%
Bad engine maintenance	11%
Negligent lookout	9%
Faulty maintenance of hull and equipment	7%

The above-mentioned represent the five major causes of all accidents.

The remaining 44% include abnormal weather, negligence of weather and sea conditions, unconfirmed vessel's position, fault of other vessels, against sailing rules, bad port and harbour facilities, etc. As a whole, it should be carefully noted that human factors such as unskilled ship manoeuvring, erroneous engine operation, bad engine maintenance, negligent lookout, faulty maintenance of hull and equipment, negligence of weather and sea conditions, unconfirmed vessel's position, against sailing rules, etc. account for as much as 82.8%, and non-human factors such as abnormal weather, etc. account for 17.2% of the total number of accidents.

ii) Relationship Between the Position of Vessels in a Convoy and Risk Level

The results of the study show that the risk level was relatively high for the vessels in the first 40% of convoys for collision accidents, and for the vessels in the rear section, 40 to 100% from the front of a convoys, for grounding accidents.

iii) Relationship Between the Number of Vessels in Convoys and Risk Level

The risk level of grounding accidents was relatively high for convoys consisting of 21 to 25 and 6 to 10 vessels, and one third of total grounding accidents occurred convoys consisting of 21 to 25 vessels.

iv) Relationship Between the Place of Accident and Time of the Day whether it was Daytime or Nighttime

Collision accidents were concentrated in Port Said where the number of accidents in daytime and those in nighttime were 10 and 7.

Frequency of grounding accident was highest in El Ballah where the number of accidents in daytime and nighttime were 14 and 7.

As for total number of grounding accidents, 33 occurred in daytime and 24 in nighttime.

The ratio of accidents in daytime to nighttime was approximately 2:1 for all accidents.

v) Relationship Between the Place of Accident and Direction of Transit

As mentioned above, collision accidents are heavily concentrated in Port Said and its associated waters where the number of such accidents northbound and southbound was 9 and 4.

When the subject comes to grounding accidents, the number is heavily biassed by southbound vessels as can be seen in the data of 13 northbound, 46 southbound, and mostly occurred at El Ballah.

vi) Gross Tonnage of Vessels and Risk Levels

The distribution of gross tonnages of transit vessels and risk levels were fairly level. Thus it may be said that the size of vessels had no direct relation with the risk level.

vii) Ship Type and Risk Levels

As in the case of the relationship between gross tonnage distribution and risk levels, distribution of ship types and risk levels were extremely even. Thus there was no specific relationship between ship type and risk level.

viii) Relationship between Vessel Movement and Frequency of Accidents

Of 27 total cases of collisions, 20 occurred either in berthing operations or in anchoring/heaving up anchor operations.

Of 61 total cases of grounding, 38 occurred during passage, and 20 either in berthing operations or in anchoring/heaving up anchor operations.

As a whole, 102 cases occurred whilst underway, 59 in berthing/anchoring/heaving-up anchor operations, and the number of accidents which occurred at anchor or berth was 20.

ix) Summary of Accident Analysis

The following may be pointed out on the basis of the results of accident analysis:

(a) Influence of Other Vessels

49 out of 55 cases of grounding occurred without the influence of other vessels, therefore, it may be said that there was no significant influence of other vessels on grounding accidents.

(b) Use of Radar

3 vessels were using radar while 19 vessels were not using radar when collision accidents occurred; 29 were using but 26 were not using radars when grounding accidents took place.

As a whole, in 45 cases out of 79 cases, no radars were in use when accidents occurred.

(c) Use of Remote Control Mode of Engine Operation

In 54 cases, the majority of the total 79 accidents, vessels were under the manual engine operation when accidents occurred.

(d) Speed of Vessels Involved in Accidents

For collision accidents, in 12 out of 22 cases vessels collided at a speed range of 0 knots and 0 to 2 knots, whereas in 5 cases vessels collided at 6 to 8 knots.

As for groundings, 20 out of 56 vessels grounded at a speed range of 6 to 8 knots, followed by 14 cases in the speed range of 0 to 2 knots.

(e) Measures Taken for Preventing Accidents

The steps taken for collision avoidance were speed reduction in 8 out of 19 cases, and steering attempts in 6.

In the case of grounding accidents, speed reduction took place in 34 out of 55 cases, and steering attempts in 9.

As a whole, in 42 out of 74 cases vessels' speed was reduced, and in 15 steering attempts took place.

(f) Locations of Grounding Accidents

In 41 out of 56 cases, grounding accidents occurred at the Canal banks, whereas 15 cases took place in shallow waters.

(g) Status at Time of Collision

As for collision accidents between vessels, crossing and overtaking situations were nearly even.

Almost all collisions were caused by meetings with other vessel.

Objects of collisions were mainly tugs, which were 9 out of 27 cases, followed by 6 cases with cargo vessels and 6 cases with vessels of other type. There were 2 cases of collision with dredgers and one case with a ferry. There were no collisions with tankers.

(5) Environmental Conditions

The population for the analysis is shown in Table V-1-(5)-1. The table shows both present population and future projections. The future population, around the year 2000, is estimated using the growth rate from 1976 to 1983 which, according to SCA, is 2.09% per year.

Table V-1-(5)-1 Population (in 1,000s)

Area \ Year	1983	2000
Port Said	90.6	128.8
El Kantara	1.1	1.6
El Ferdan	0.5	0.7
Ismailia (coastal area)	19.6	27.9
West Shore of Great Bitter Lake	46.9	66.6
Area I	15.2	21.6
Area II	12.5	17.8
Area III	12.2	17.3
Area IV	7.0	9.9
Suez	33.8	48.0

As for the water quality of the Canal, oily matter could not be extracted from the samples gathered during the first field survey, and it can be said that the water quality as a basic condition will be almost the same as reported in Part II, II-7.

Table V-1-(5)-2 shows the basic conditions of the water quality of the Canal.

Table V-1-(5)-2 Basic Conditions of Water Quality

Item Location		COD (mg/ℓ)	Cl^- (o/oo)	PH	SS (mg/ℓ)	DO (mg/ℓ)	Temperature (°C)	OCB (mg/ℓ)
Hm 50	West Entrance	5.2	20.4	8.1	22.9	5.5	24.6	ND
Hm 30	Near Tip of East Breakwater	4.8	20.4	8.2	–	5.3	24.8	–
Km 2	In Harbour	5.0	20.6	8.1	18.4	4.2	25.1	ND
Km 14	West Channel	5.4	20.6	8.0	19.6	4.1	25.0	–
Km 25		4.6	21.5	8.1	12.2	5.2	25.5	–
Km 35		3.4	22.7	8.2	9.5	5.5	25.6	ND
Km 45		4.2	22.7	8.2	–	5.2	25.5	–
Km 55	West Branch	4.2	23.4	8.1	6.8	5.9	25.5	–
Km 62.5	Near Juncture	4.0	23.3	8.2	4.8	5.9	25.9	–
Km 77	Near Sailing Club	5.2	22.9	8.1	6.7	5.8	25.8	–
Km 78	West Said	7.2	14.8	8.0	6.3	5.9	25.1	ND
Km 87		5.4	23.0	8.2	6.7	5.9	25.7	–
Km 97.5	West Branch	4.2	24.6	8.2	6.5	6.1	25.8	ND
Km 104	West Side of-Great Bitter Lake	4.9	23.8	8.3	11.1	7.6	25.8	–
Km 111	– ditto –	3.8	23.8	8.2	–	7.1	26.0	ND
Km 121	West Branch	3.2	24.4	8.3	65.6	6.5	25.2	–
Km 128	West Side of Little Bitter Lake	2.8	24.7	8.2	25.4	5.9	24.8	ND
Km 134.5	Entrance to Little Bitter Lake	3.3	24.4	8.2	8.6	5.9	24.3	ND
Km 146		4.2	24.5	8.2	6.5	5.7	24.2	ND
Km 160	In Harbour	4.2	24.5	8.2	7.5	5.8	24.0	–
Hm 47.5	Near Oil Berth	7.4	24.6	8.2	5.0	5.9	24.0	ND

Note: The "ND" means that the oily matter could not be extracted.

(6) Studied Cases (Location and Accident types)

Risk Analysis was made on potential vessel accidents in the canal. Accident types and locations considered in this report are summarized in Table V-1-(6)-1 and Fig. V-1-(6)-1. In the same table the models which were used to estimate risk levels are introduced.

Table V-1-(6)-1 Study Locations and Accident Types

Type	Location	
Grounding	– Throughout the Canal.	
	– Bypass	
	– Main channel	
Collision	• Rear-end collision	
	– Throughout the Canal	
	• Between vessels	
	– Cross at Port Said Approach Channel and East Bypass	A
	– Junctions	B, C, D
	– Around South Light and North Light	F, F
	– Waiting area at Great Bitter Lake and Port Said	M, I
	• Between a vessel and a dredger	
	– Throughout the Canal	
Secondary Disasters	• Diffusion of spilled oil	
	– Port Said	A
	– Great Bitter Lake	I
	– Suez	G

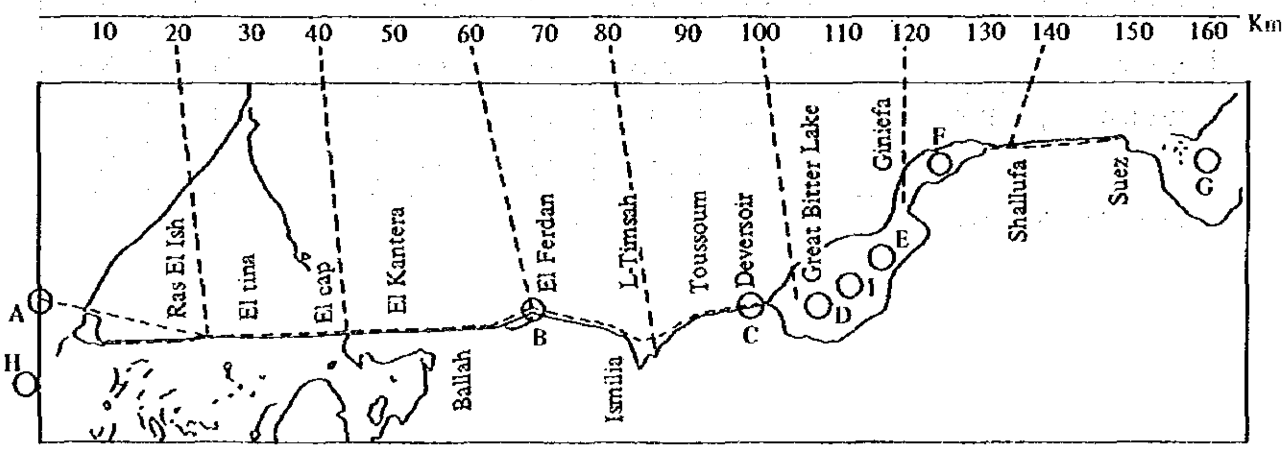


Fig. V-1-(6)-1 Study Locations

V-2 Estimation Results

(1) Estimation of Probability

1) Grounding

(i) General Structure of the Grounding Model

Grounding accidents happen when vessels fail to keep their center and touch the canal banks. This phenomenon is explained by the vessel track model which is composed using SCVTMS data on the Canal.

Fig. V-2-(1)-1 shows the procedure for obtaining grounding probability.

This procedure can be divided into the following parts:

i) Characteristics of vessel tracks
ii) Determination of risky zones
iii) Failure probability of escaping action

In brief, the probability of vessels passing the critical line at which they have to take an escaping action is calculated, and a final probability of grounding accidents is estimated by considering the failure probability of escaping. The critical zone is determined by external conditions such as canal topography, maneuvering capability and natural conditions. At curving parts, an additional Ym is necessary to calculate the critical zone.

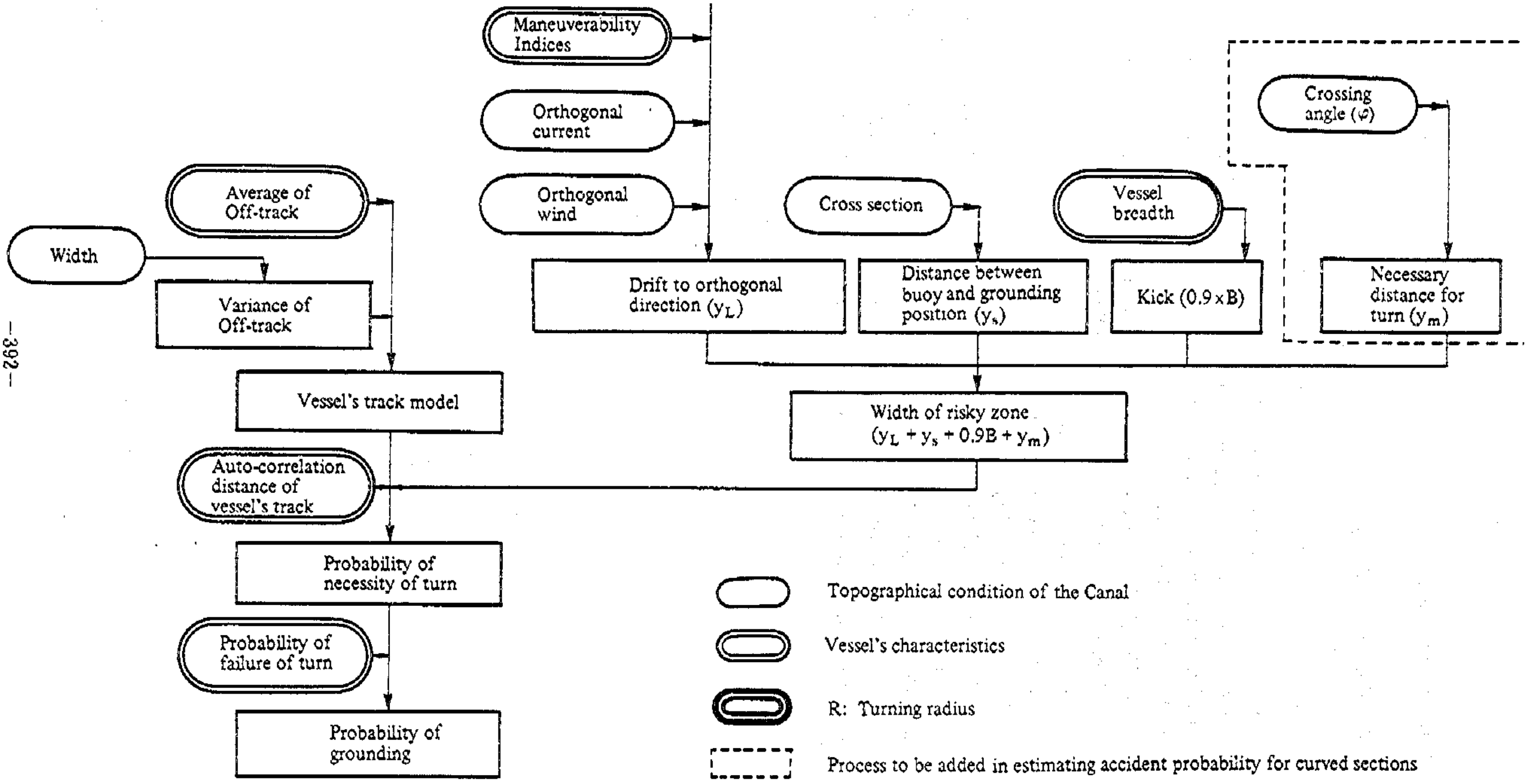


Fig. V-2-(1)-1 Estimation Procedure for Grounding Accidents

(ii) Calculation Premises

i) Locations

The whole Canal is divided into sections as shown in Fig. V-2-(1)-2. All locations within each section have the same characteristics, both in topographical conditions and in the vessels' tracks. So, the accident probability is estimated for each section.

ii) Vessel Classification

Various vessel characteristics which differ according to vessel type have a minimal effect on grounding probabilities when compared with the vessel size. Therefore, in this study, only vessel size is taken into account. Following is a list of the size categories. The sizes in brankets are representative sizes.

1 ~ 10,000 DWT (5,000 DWT)
2 10,000 ~ 50,000 DWT (10,000 DWT & 50,000 DWT)
3 50,000 DWT ~ (100,000 DWT)

Grounding probabilities are estimated for each vessel size.

Table V-2-(1)-1 Dimensions by Vessel Size

Categories	Representative	Dimension			Loaded Draft (m)
		L (m)	B (m)	U (m)	
0 ~ 10,000 DWT	5,000 DWT	103.0	14.7	7.6	6.9
10,000 DWT ~ 50,000 DWT	10,000 DWT	139.0	19.0	9.9	8.1
	50,000 DWT	226.0	32.1	16.5	12.5
50,000 DWT ~	100,000 DWT	270.0	39.0	19.2	14.6

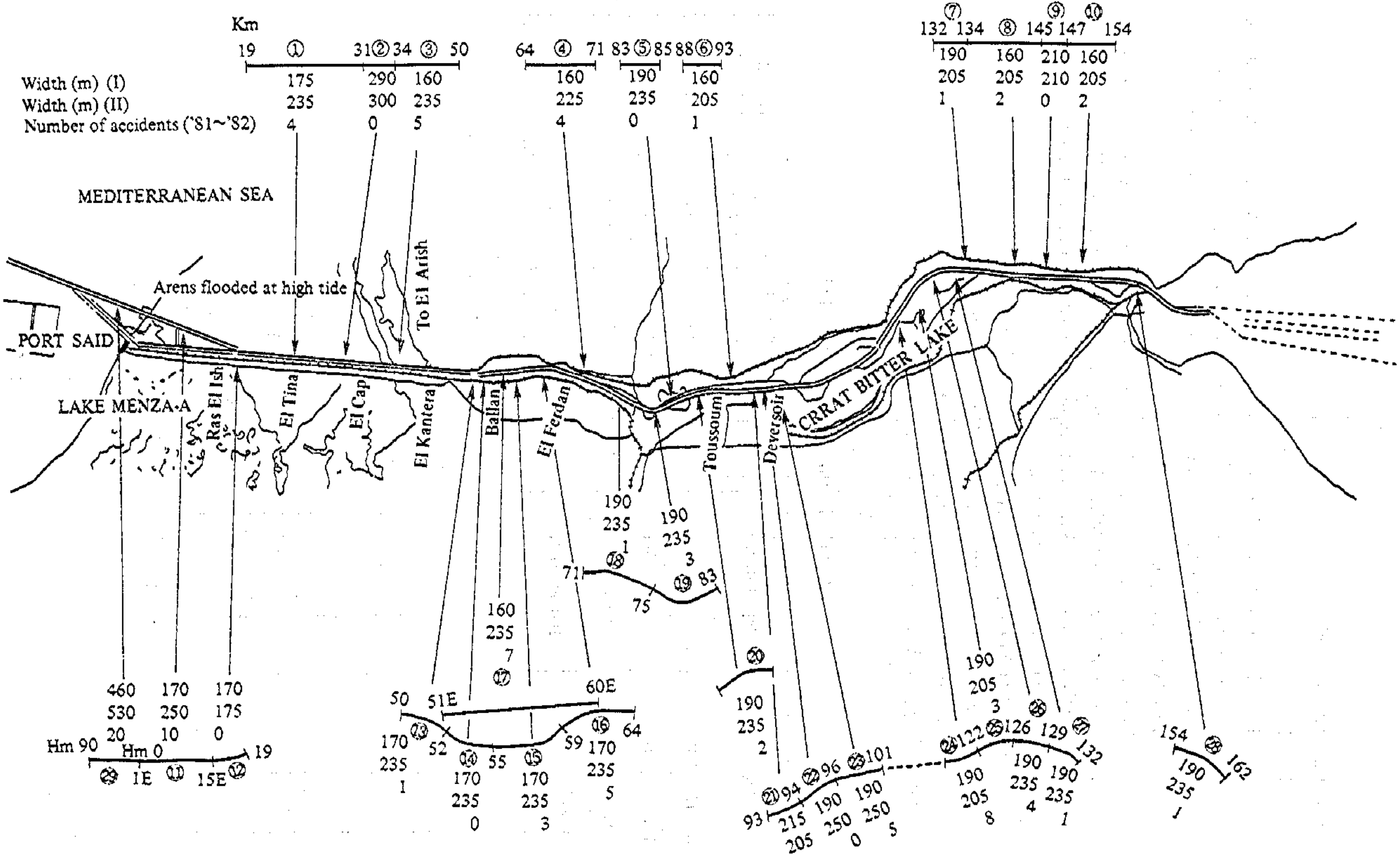


Fig. V-2-(1)-2 Studied Sections (① ~ ㉙)

]

(iii) Model Specification

i) Vessel Track Model

The position which a vessel takes can be expressed by the distance from the center line of the Canal at each location x as is shown in Fig. V-2-(1)-3.

The vessel track model explains the characteristics of the distribution of a vessel's position, and is expressed by the following probabilistic position of a vessel.

$y(x) = \mu(x) + \sigma(x) \cdot u(x)$

$y(x)$; Vessel's position expressed by the distance from the center line

$\mu(x)$; Mean $y(x)$

$\sigma(x)$; Deviation of $y(x)$

$u(x)$; Standardized gaussion process

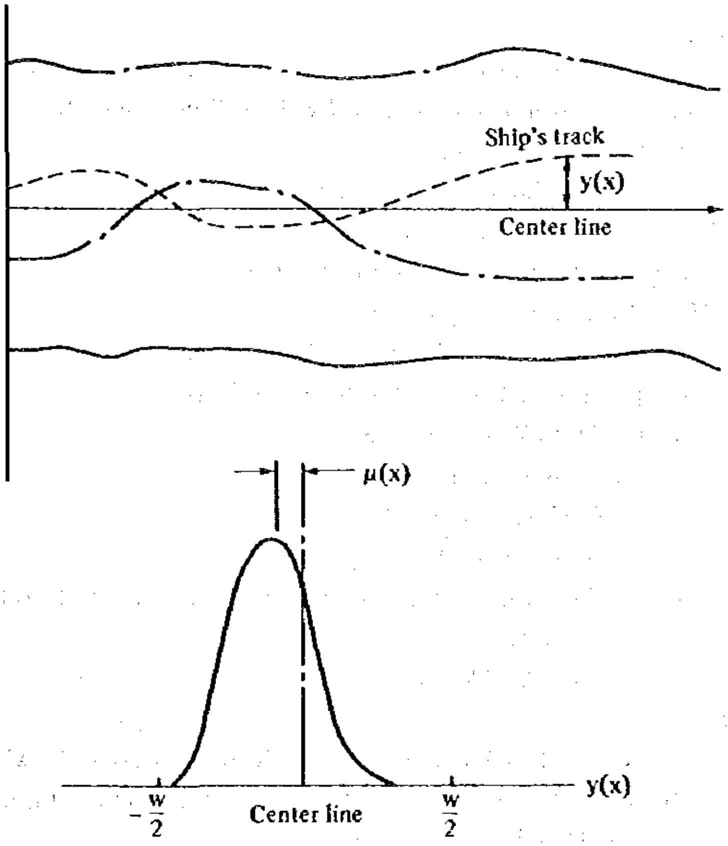


Fig. V-2-(1)-3 Vessel Track Model

The track model is specified by parameters $\sigma(x)$ and $\mu(x)$. It is empirically known that the standardized deviation of a vessel's position is correlated with the channel's width as in the following equation:

$\sigma(x) = a + b \cdot w(x)$

$w(x)$: channel width

Parameters a and b are specified as a = 6.58, b = 0.092 from the SCVTMS data of the Canal.

ii) Determination of Critical Zone

In the grounding model, a critical zone is introduced beyond which a vessel has to turn to escape touching the bank. The distance between buoys and the critical line Yc differs between straight parts (yc_1) and curved parts (yc_2).

(a) Straight Parts

In the straight parts Yc_1 is expressed as follows.

$yc_1 = y_L + y_B + ys$

y_L : Maximum drift movement to the diagonal direction

y_B : Kick

ys : Distance between buoys and the position where a vessel touches the bank

The components y_L, y_B and ys are shown in the Fig. V-2-(1)-4

① y_L

y_L is due to external forces which affect the time necessary until a vessel begins to turn. It is expressed by the following equation.

$y_L = T\,(c \cdot Vw + Vc)$

T : Time delay for starting the turn

Vw : Wind velocity (m/s)

c : Coefficient for wind pressure (c)

Vc : Current velocity (m/s)

T and c are empirically set as follows from previous literature:*1)

$T = [15 \text{ Log}(DWT) - 47] \times \sqrt[3]{DWT} / v$ (s)

DWT : Dead Weight Tonnage

v : Vessel speed

c = 0.05 (non-tanker)*2)

0.04 (tanker)

Note: *1) Channel width of Harbour Entrance; Yukito Iijima and Keinosuke Honda

*2) JAPMA data

② y_B

y_B is so called kick, that is the degree vessels slide when turning, and this study uses the following relation from previous literature.*3)

$y_B = 0.9 \times B$

The above equation is deduced by the followings.

The kick yx changes with rudder angle ϕ, and y_B is the maximal kick is one operation for course change. y_B is expressed as follows.

$$yx = \frac{3}{4}\ell \sin\phi + \frac{B}{2} \cdot \cos\phi - R\,(1 - \cos\phi)$$

To maximize yx, ϕ has to satisfy

$$\tan\phi = \frac{3}{4}\ell \,/\, (\frac{B}{2} + R)$$

Then y_B is obtained by the following expression:

$$y_B = \frac{3}{4}\ell \sin\phi + \frac{B}{2}\cos\phi - R(1 - \cos\phi)$$

where R: Curvature (m)

ϕ: $\tan^{-1}\frac{3}{4}\ell / (B/2 + R)$

ℓ: Length of vessel

If $R = 4.5\ell$ and $B/\ell = 6.5$ are given as typical vessel size, $y_B = 0.9 \times B$ is obtained.

Note: *3) Same literature as *1) above

③ ys

ys is determined by topographical conditions and vessel size.

$$ys = \begin{cases} 0 & (d \leqq 11 \text{ m}) \\ \text{distance between buoys and the position where vessels touch the bank} & (d \geqq 11 \text{ m}) \end{cases}$$

d : Vessel's draft

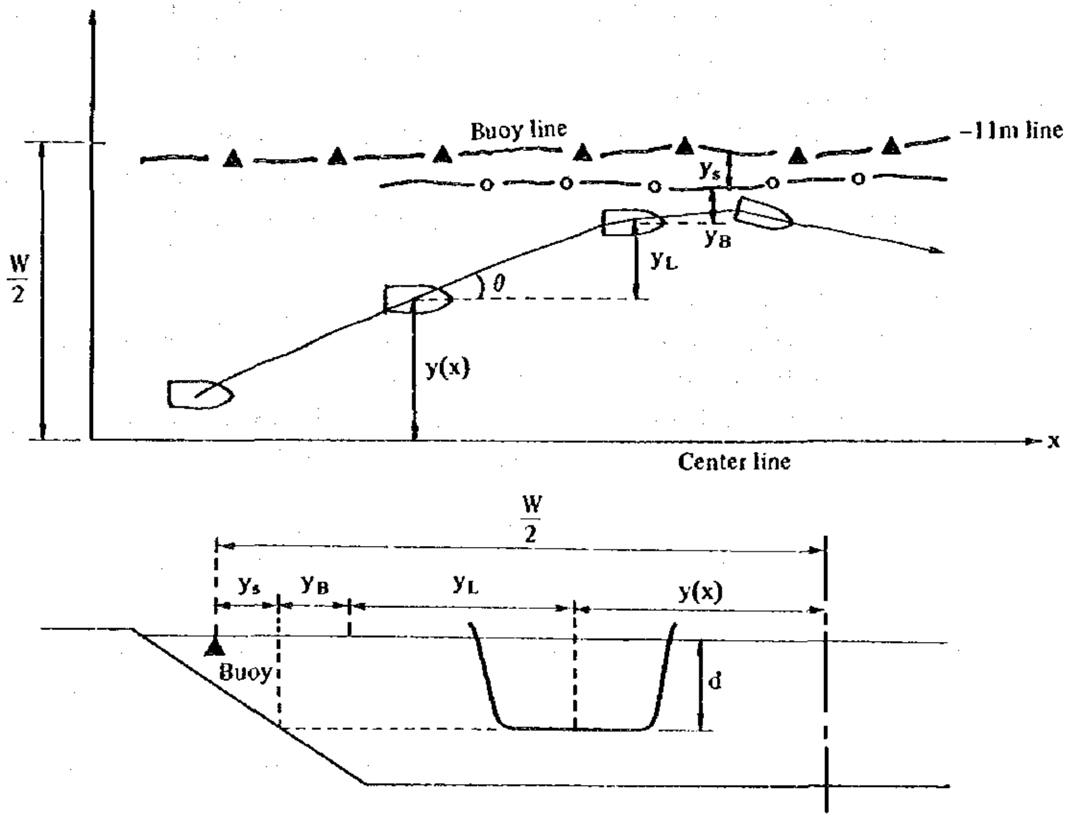


Fig. V-2-(1)-4 Components of Risky Zone

(b) Curving Parts

Suppose that a direction changes through a curving part by φ, a critical zone for the part y_{c2} is approximately defined as the following equation.

$$y_{c2} = y_{c1} + V \cdot T \sin \frac{\varphi}{2}$$

The above equation is deduced as following way.

At curving part, an operater takes, mainly, following actions. Firstly, he turns a rudder to take a course along the curve. Then, next, at a certain point in the curve, he returns the rudder to get out of the circuit.

After getting out of the circuit, the vessel advances straight with a direction θ, which is tangent of the circuit, to the new channel. This θ changes in order that $\theta = 0$ when the operater navigates best and that $\theta = \varphi$ when he returns the rudder, badly, at the very beginning of the circuit. Therefore, generally, θ takes the following range.

$$0 \leq \theta \leq \varphi$$

Lastly, he has to adjust θ, change a course by θ along the new straight channel. It takes a time delay T, then the vessel approaches to the diagonal direction to the new channel by VT sin θ.

The above VT sinθ is added to y_{c1} of the new straight channel for the critial zone at the curving part as for θ, we took $\varphi/2$ as a center value of the above range. Then y_{c2} is composed of VT sin $\varphi/2$ and y_{c1} for the curving part.

iii) Risky Zones and Safe Zones

By using the critical line defined above, risky zones and safe zones can be determined. In this study risky zones and safe zones are defined as the areas from the critical line to the buoys and from the critical zone to the center line respectively. These zones are shown in Fig. V-2-(1)-5.

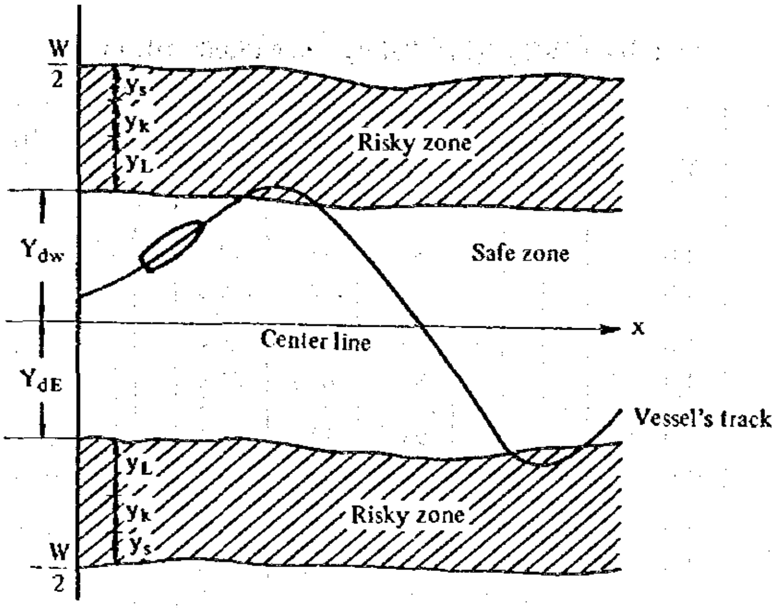


Fig. V-2-(1)-5 Safe Zones and Risky Zones

The distance between the center line and the inner side of the risky zone is expressed by the following equation.

$$Ydw = \frac{W}{2} - Ycw = \frac{W}{2} - (Ys + Yk + Y_L + Ym)\ w$$

$$Yd_E = \frac{W}{2} - YcE = \frac{W}{2} - (Ys + Yk - Y_L + Ym)_E$$

Where W and E denotes the west and east side of the Canal. To obtain Ydw, Yd_E, the following data are used:

① Y_L (= T (c · Vw + Vc))
- Drifting time (T)
- Wind velocity (From observed data in the Canal)
- Current velocity (from observed data)
- Coefficient for wind pressure (0.05 for non tankers and 0.04 for tankers)

② Yk (= B x 0.9)
- Vessel breadth (B) (Shown in Table V-2-(1)-1)

③ Ys
- Vessel draft (Shown in Table V-2-(1)-1)
- Canal depth (from cross section diagram)

④ Ym
- Vessel speed (V) (From observed data in the Canal)
- Drifting time (T)
- Crossing angle (φ) (From observed data)

⑤ Yd_E, Ydw
- Canal width (Shown in Table V-2-(1)-1)

The data necessary to calculate the safe zone and the results are shown in Tables V-2(1)-2 (1) ~ (4) by vessel size.

Table V-2-(1)-2(1) Safety Zone (5,000 DWT)

No.	Vw	Vc	Y_L	Yk	(I)				(II)			
					Ys	W/2	Ydw	YdE	Ys	W/2	Ydw	YdE
1	-0.77	0	-1.0	13.2	0	87.5	75.2	73.3	0	117.5	105.2	103.3
2	-0.77	0	-1.0			145	132.7	130.8		150	137.7	135.8
3	-0.77	0	-1.0			80	67.7	65.8		117.5	105.2	103.3
4	-0.77	0	-1.0			80	67.7	65.8		112.5	100.2	98.3
5	-0.77	0	-1.0			95	82.7	80.8		117.5	105.2	103.3
6	-0.77	0	-1.0			80	67.7	65.8		102.5	90.2	88.3
7	-0.77	0	-1.0			95	82.7	80.8		102.5	90.2	88.3
8	-0.77	0	-1.0			80	67.7	65.8		102.5	90.2	88.3
9	-0.77	0	-1.0			105	92.7	90.8		105	92.7	90.8
10	-0.77	0	-1.0			80	67.7	65.8		102.5	90.2	88.3
11	-0.77	0.012	-0.6			87.5	72.4	71.2		125	112.4	111.2
12	-0.77	0	-1.0			87.5	75.2	66.2		87.5	75.2	66.2
13	-0.77	0	-1.0			87.5	65.6	70.8		117.5	98.1	103.3
14	-0.77	0	-1.0			87.5	72.7	63.7		117.5	105.2	96.2
15	-0.77	0	-1.0			87.5	72.7	63.7		117.5	105.2	96.2
16	-0.77	0	-1.0			87.5	65.7	70.8		117.5	98.2	103.3
17	-0.77	0	-1.0			80	67.7	65.8		117.5	105.2	103.3
18	-0.77	0	-1.0			95	75.9	80.8		117.5	98.4	103.3
19	-0.77	0	-1.0			95	82.7	73.4		117.5	105.2	95.9
20	-0.77	0	-1.0			95	71.9	82.7		117.5	94.4	105.2
21	-0.77	0	-1.0			107.5	95.2	86.2		102.5	95.2	86.2
22	-0.77	0	-1.0			95	75.6	80.8		125	105.6	110.8
23	-0.77	0.006	-0.8			95	82.6	81.0		125	112.55	111.0
24	5.40	-0.01	6.5			95	75.3	88.2		102.5	82.8	95.7
25	2.32	-0.008	4.6			95	68.4	84.4		102.5	75.9	91.9
26	2.32	0.003	3.0			95	78.8	84.8		117.5	101.3	107.3
27	0.77	0.038	2.2			95	69.5	83.9		117.5	92.0	106.4
28	2.32	0.005	3.1			95	67.7	84.8		117.5	90.2	107.3
29	-0.77	0.023	-0.5			230	217.3	209.2		265	252.3	244.2

Note: (I): The First Stage Development Project
(II): The Second Stage Development Project

Table V-2-(1)-2(2) Safety Zone (10,000 DWT)

No.	Vw	Vc	Y_L	Yk	(I)				(II)			
					Ys	W/2	Ydw	YdE	Ys	W/2	Ydw	YdE
1	-0.77	0	-1.9	17.1	0	87.5	72.3	68.5	0	117.5	102.3	98.5
2	-0.77	0	-1.9			145	129.8	126.0		150	134.8	131.0
3	-0.77	0	-1.9			80	64.8	61.0		117.5	102.3	98.5
4	-0.77	0	-1.9			80	64.8	61.0		112.5	97.3	93.5
5	-0.77	0	-1.9			95	79.8	76.0		117.5	102.3	98.5
6	-0.77	0	-1.9			80	64.8	61.0		102.5	87.3	83.5
7	-0.77		-1.9			95	79.8	76.0		102.5	87.3	83.5
8	-0.77	0	-1.9			80	64.8	61.0		102.5	87.3	83.5
9	-0.77	0	-1.9			105	89.8	86.0		105	89.8	86.0
10	-0.77	0	-1.9			80	64.8	61.0		102.5	87.3	83.5
11	-0.77	0.012	-1.1			87.5	69.0	66.8		125	109.0	106.8
12	-0.77	0	-1.9			87.5	72.3	59.5		87.5	72.3	59.5
13	-0.77	0	-1.9			87.5	60.8	66.0		117.5	93.3	98.5
14	-0.77	0	-1.9			87.5	69.8	57.0		117.5	102.3	89.5
15	-0.77	0	-1.9			87.5	69.8	57.0		117.5	102.3	89.5
16	-0.77	0	-1.9			87.5	60.9	66.0		117.5	93.4	98.5
17	-0.77	0	-1.9			80	64.8	61.0		117.5	102.3	98.5
18	-0.77	0	-1.9			95	71.2	76.0		117.5	93.8	98.5
19	-0.77	0	-1.9			95	79.8	66.4		117.5	102.3	88.9
20	-0.77	0	-1.9			95	63.6	79.8		117.5	86.1	102.3
21	-0.77	0	-1.9			107.5	92.3	79.5		102.5	92.3	79.5
22	-0.77	0	-1.9			95	70.8	76.0		125	100.8	106.0
23	-0.77	0.006	-1.5			95	79.4	76.4		125	109.4	106.4
24	5.40	-0.01	12.5			95	65.4	90.4		102.5	72.9	97.9
25	2.32	-0.008	8.9			95	56.9	83.0		102.5	64.4	90.5
26	2.32	0.003	5.8			95	72.1	83.7		117.5	94.6	106.2
27	0.77	0.038	4.2			95	58.9	82.1		117.5	81.5	104.6
28	2.32	0.005	5.9			95	55.5	83.8		117.5	77.9	106.3
29	-0.77	0.023	-0.9			230	213.8	203.0		265	248.8	238.0

Note: (I): The First Stage Development Project
(II): The Second Stage Development Project

Table V-2-(1)-2(3) Safety Zone (50,000 DWT)

No.	Vw	Vc	Y_L	Yk	(I)				(II)			
					Ys	W/2	Ydw	YdE	Ys	W/2	Ydw	YdE
1	-0.77	0	-5.8	28.9	6.0	81.5	58.4	46.8	6.0	111.5	88.4	76.8
2	-0.77	0	-5.8		6.0	139	115.9	104.3	6.0	144	120.9	109.3
3	-0.77	0	-5.8		6.0	74	50.9	39.3	6.0	111.5	88.4	76.8
4	-0.77	0	-5.8		4.4	75.6	52.5	40.9	4.4	108.1	85.0	73.4
5	-0.77	0	-5.8		4.5	90.5	67.4	55.8	4.5	113.0	89.9	78.3
6	-0.77	0	-5.8		3.75	76.25	53.1	41.6	3.8	108.7	75.6	64.0
7	-0.77	0	-5.8		4.5	90.5	67.4	55.8	4.4	98.1	75.0	63.4
8	-0.77	0	-5.8		4.4	75.6	52.5	30.9	4.4	98.1	75.0	63.4
9	-0.77	0	-5.8		4.5	100.5	77.4	65.8	4.5	100.5	77.4	65.8
10	-0.77	0	-5.8		4.4	75.6	52.5	40.9	4.4	98.1	75.0	63.4
11	-0.77	0.012	-3.6		6.0	81.5	53.6	46.6	6.0	119	93.6	86.6
12	-0.77	0	-5.8		6.0	81.5	58.4	32.9	6.0	81.5	58.4	32.9
13	-0.77	0	-5.8		6.0	81.5	42.0	44.3	6.0	111.5	74.5	76.8
14	-0.77	0	-5.8		6.0	81.5	55.9	30.4	6.0	111.5	88.4	62.9
15	-0.77	0	-5.8		6.0	81.5	55.9	30.5	6.0	111.5	88.4	62.9
16	-0.77	0	-5.8		6.0	81.5	42.4	44.3	6.0	111.5	74.9	76.8
17	-0.77	0	-5.8		6.0	74.0	50.9	39.3	6.0	111.5	88.4	76.8
18	-0.77	0	-5.8		4.4	90.6	54.9	55.9	4.4	113.1	77.4	78.4
19	-0.77	0	-5.8		4.5	90.5	67.4	40.4	4.5	113.0	89.9	62.9
20	-0.77	0	-5.8		4.5	90.5	31.2	67.4	4.5	113.0	53.7	89.9
21	-0.77	0	-5.8		3.8	103.7	80.6	55.1	3.8	98.7	80.6	55.1
22	-0.77	0	-5.8		4.4	90.6	53.6	55.9	4.4	120.6	83.6	85.9
23	-0.77	0.006	-4.6		4.5	90.5	66.3	56.9	4.5	120.5	96.3	87.0
24	5.40	-0.01	38.6		4.4	90.6	23.1	61.7	4.4	98.1	30.6	69.2
25	2.32	-0.008	27.4		4.5	90.5	10.6	77.5	4.5	98.0	18.1	85.0
26	2.32	0.003	18.0		4.5	90.5	43.7	79.6	4.5	113.0	66.2	102.1
27	0.77	0.038	12.9		4.5	90.5	16.9	74.5	4.5	113.0	39.5	97.0
28	2.32	0.005	18.3		4.5	90.5	6.0	79.9	4.0	113.5	28.6	102.4
29	-0.77	0.023	-2.9		15.0	215	189.0	169.4	15.0	250	224.0	204.4

Note: (I): The First Stage Development Project
(II): The Second Stage Development Project

Tavle V-2-(1)-2(4) Safety Zone (100,000 DWT)

No.	Vw	Vc	Y_L	Yk	(I)				(II)			
					Ys	W/2	Ydw	YdE	Ys	W/2	Ydw	YdE
1	-0.77	0	-8.7	35.1	14.4	73.1	46.7	29.3	14.4	103.1	76.7	59.3
2	-0.77	0	-8.7		14.4	130.6	104.2	86.8	14.4	135.6	109.2	91.8
3	-0.77	0	-8.7		14.4	65.6	39.2	21.8	14.4	103.1	76.7	59.3
4	-0.77	0	-8.7		10.7	69.3	42.9	25.5	10.7	101.8	75.4	58.0
5	-0.77	0	-8.7		10.8	84.2	57.8	40.4	10.8	101.7	80.3	62.9
6	-0.77	0	-8.7		9.05	70.95	44.5	27.2	9.0	93.5	67.0	49.7
7	-0.77	0	-8.7		10.8	84.2	57.8	40.4	10.7	91.8	65.4	48.0
8	-0.77	0	-8.7		10.7	69.3	42.9	25.5	10.7	91.8	65.4	48.0
9	-0.77	0	-8.7		10.8	94.2	67.8	50.4	10.8	94.2	67.8	50.4
10	-0.77	0	-8.7		10.7	69.3	42.9	25.5	10.7	91.8	65.4	48.0
11	-0.77	0.012	-5.3		14.4	73.1	40.8	30.2	14.4	110.6	80.8	70.2
12	-0.77	0	-8.7		14.4	73.1	46.7	13.4	14.4	73.1	46.7	13.4
13	-0.77	0	-8.7		14.4	73.1	28.2	26.8	14.4	103.1	60.7	59.3
14	-0.77	0	-8.7		14.4	73.1	44.2	10.8	14.4	103.1	76.7	43.3
15	-0.77	0	-8.7		14.4	73.1	44.2	10.9	14.4	103.1	76.7	43.4
16	-0.77	0	-8.7		14.4	73.1	28.8	26.8	14.4	103.1	61.3	59.3
17	-0.77	0	-8.7		14.4	68.6	39.2	21.8	14.4	103.1	76.7	59.3
18	-0.77	0	-8.7		10.7	84.3	43.7	40.5	10.7	106.8	66.2	63.0
19	-0.77	0	-8.7		10.8	84.2	57.8	22.2	10.8	106.7	80.3	44.7
20	-0.77	0	-8.7		10.8	84.2	8.3	57.8	10.8	106.7	30.8	80.3
21	-0.77	0	-8.7		19.1	88.4	72.0	38.7	9.1	93.4	72.0	38.7
22	-0.77	0	-8.7		10.7	84.3	41.9	40.5	10.7	114.3	71.9	70.5
23	-0.77	0.006	-7.0		10.8	84.2	56.1	42.1	10.8	114.2	86.1	72.1
24	5.40	-0.01	-58.0		10.8	84.2	-8.8	49.2	10.7	91.8	0	56.7
25	2.32	-0.008	41.2		10.9	84.1	-22.7	73.0	10.8	91.7	0	80.5
26	2.32	0.003	27.0		10.8	84.2	22.1	76.0	10.8	106.7	44.6	98.6
27	0.77	0.038	19.4		10.8	84.2	-13.1	68.5	10.8	106.7	9.4	91.0
28	2.32	0.005	27.5		10.8	84.2	-29.5	76.6	10.8	106.7	0	99.1
29	-0.77	0.023	-4.4		36.0	194	163.3	138.6	36.0	229	198.3	173.6

Note: (I): The First Stage Development Project
(II): The Second Stage Development Project

(iii) Probability of Grounding

i) Probability of Necessity of Give-way (P_R)

(a) Arithmetic Formulation

If a vessel gets into the risky zone, she has to give-way promptly. Here the probability that a vessel gets into the risky zone or exceeds the critical line is formulated. The probability P_R is based on how many times a vessel track passes the critical line, and is expressed by the equation below. In other words, it is expressed by the ratio of the number of the locations at which the vessel exceeds the critical line over the length of the studied location.

$$P_R = N(Y(x) \geqq Yd) \times \ell$$

N (·) : Number of locations at which · is satisfied
Yd : Width of the safe zone (Yd_W or Yd_E)
ℓ : Length of the part which is studied (km)

The expected number is obtained by the following equation from the application of stochastic process analysis.

$$N(Yd) = \frac{1}{2\pi}\sqrt{\frac{m_2}{mo}}\,e^{-(Yd^2/2mo)}$$

N (Yd) : Expected number of cases at which a vessel track passes the critical line
Yd : Distance from center line to the critical line
mo : *$\sigma_y{}^2$, variance of the vessel track*
m2 : $\sigma_{\dot{y}}{}^2$, variance of the gradient of vessel track, expressed by $(2/h^2)$, where h is the auto-correlation coefficient of the vessel track.

So, the probability that a vessel has to make give-way action is estimated for each section of the Canal by $\sigma_y{}^2$, h^2 which reflects the characteristics of the track and dc which reflects the natural or topographical condition of the part (Fig. V-2-(1)-6).

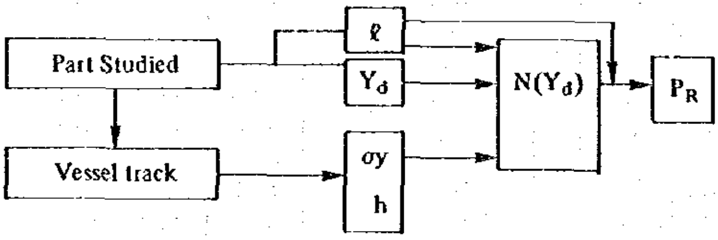


Fig. V-2-(1)-6 Probability for Necessity of Give-way

(b) Data

To obtain the above probability for necessity of give-way the following data are used:

1 $Mo = \sigma_y{}^2 = 514.38$ from SCVTMS vessel data

2 $m_2 = \sigma_{\dot{y}}{}^2 = \frac{2}{h^2} = 9{,}549 \times 10^{-7}$

(h = 1,447 m from SCVTMS vessel data)

3 The length of each division ℓ is shown in Table V-2-(1)-3 with calculation

results.

(c) Calculation Results

Probabilities for necessity of give-way are obtained as shown in Table V-2-(1)-3.

ii) Probability of Failure of Give-way (P_F)

When a vessel enters the risky zone, failure of give-way leads to a grounding accident. This failure is due to various kinds of machine and human errors, which are difficult to be estimated analytically. In this study the probability of failure of give-way (P_F) is obtained by an empirical approach.

$$P_F = \frac{P_{G(I)}}{P_R}$$

$P_{G(I)}$: Observed probability of grounding accidents

$P_{G(I)}$ is obtained as Table V-2-(1)-6 from accident data record by SCA. Then the above equation gives failure probabilities of give-way. The result is shown in Table V-2-(1)-4.

iii) Probability of Grounding ($P_{G(I)}$ and $P_{G(II)}$)

Grounding probabilities for phase (I) are equal to those at present. Those for phase (II) are obtained by multiplying the probability of necessity of give-way at phase (II) (P_R) and failure probability, which is assumed to be unchanged from phase I to II. Then grounding probabilities are shown in Table V-2-(1)-5.

Table V-2-(1)-3 Probabilities for Necessity of Give-way (P_R)

	km	km	5,000		10,000		50,000		100,000	
No.	Location	ℓ	I	II	I	II	I	II	I	II
1	19 ~ 31	12	7.80×10^{-4}	1.43×10^{-4}	1.37×10^{-3}	2.40×10^{-4}	1.28×10^{-2}	2.10×10^{-3}	4.56×10^{-2}	8.88×10^{-3}
2	31 ~ 34	3	1.10×10^{-5}	9.16×10^{-6}	1.76×10^{-5}	1.45×10^{-5}	1.35×10^{-4}	1.08×10^{-4}	4.53×10^{-4}	4.53×10^{-4}
3	34 ~ 50	16	1.73×10^{-3}	1.91×10^{-4}	3.08×10^{-3}	3.20×10^{-4}	2.80×10^{-2}	2.81×10^{-3}	9.07×10^{-2}	1.18×10^{-2}
4	64 ~ 71	7	7.58×10^{-4}	1.07×10^{-4}	1.35×10^{-3}	1.81×10^{-4}	1.05×10^{-2}	1.38×10^{-3}	3.17×10^{-2}	5.03×10^{-3}
5	83 ~ 85	2	8.10×10^{-5}	2.39×10^{-5}	1.41×10^{-4}	4.00×10^{-5}	1.13×10^{-3}	3.02×10^{-4}	3.88×10^{-3}	1.11×10^{-3}
6	88 ~ 93	5	5.42×10^{-4}	1.31×10^{-4}	9.61×10^{-4}	2.25×10^{-4}	7.06×10^{-3}	1.66×10^{-3}	2.03×10^{-2}	5.47×10^{-3}
7	132 ~ 134	2	8.10×10^{-5}	5.23×10^{-5}	1.41×10^{-4}	8.98×10^{-5}	1.13×10^{-3}	7.05×10^{-4}	3.88×10^{-3}	2.51×10^{-4}
8	134 ~ 145	11	1.19×10^{-3}	2.88×10^{-4}	2.11×10^{-3}	4.94×10^{-4}	1.65×10^{-2}	3.88×10^{-3}	4.98×10^{-2}	1.38×10^{-2}
9	145 ~ 147	2	4.55×10^{-5}	4.55×10^{-5}	7.79×10^{-5}	7.79×10^{-5}	6.13×10^{-4}	6.13×10^{-4}	2.20×10^{-3}	2.20×10^{-3}
10	147 ~ 154	9	7.58×10^{-4}	1.83×10^{-4}	1.35×10^{-3}	3.14×10^{-4}	1.05×10^{-2}	2.47×10^{-3}	3.17×10^{-2}	8.78×10^{-3}
11	1E ~ 15E	14	1.07×10^{-3}	1.17×10^{-4}	1.86×10^{-3}	1.92×10^{-4}	1.62×10^{-2}	1.51×10^{-3}	5.71×10^{-2}	6.17×10^{-3}
12	15E ~ 19W	2.4	3.00×10^{-4}	3.00×10^{-4}	6.28×10^{-4}	6.28×10^{-4}	6.33×10^{-3}	6.33×10^{-3}	1.58×10^{-2}	1.58×10^{-2}
13	50W ~ 52W	2.0	2.66×10^{-4}	3.93×10^{-5}	5.02×10^{-4}	7.11×10^{-5}	4.26×10^{-3}	6.06×10^{-4}	1.30×10^{-2}	2.30×10^{-3}
14	52W ~ 55W	3.0	4.45×10^{-4}	6.50×10^{-5}	9.32×10^{-4}	1.30×10^{-4}	9.11×10^{-3}	1.49×10^{-3}	2.16×10^{-2}	5.49×10^{-3}
15	55W ~ 59W	4.0	5.93×10^{-4}	8.66×10^{-5}	1.24×10^{-3}	1.74×10^{-4}	1.21×10^{-2}	1.99×10^{-3}	2.87×10^{-2}	7.31×10^{-3}
16	59W ~ 64	5.0	6.61×10^{-4}	9.78×10^{-5}	1.24×10^{-3}	1.76×10^{-4}	1.05×10^{-2}	1.48×10^{-3}	3.20×10^{-2}	5.61×10^{-3}
17	51E ~ 60E	9	9.75×10^{-4}	1.08×10^{-4}	1.73×10^{-3}	1.80×10^{-4}	1.57×10^{-2}	1.58×10^{-3}	5.10×10^{-2}	6.66×10^{-3}
18	71 ~ 75	4	2.71×10^{-4}	7.72×10^{-5}	4.98×10^{-4}	1.37×10^{-4}	3.66×10^{-3}	9.74×10^{-4}	1.12×10^{-2}	3.21×10^{-3}
19	75 ~ 83	8	6.36×10^{-4}	1.78×10^{-4}	1.36×10^{-3}	3.67×10^{-4}	1.37×10^{-2}	3.95×10^{-3}	3.67×10^{-2}	1.33×10^{-2}
20	85 ~ 88	3	2.75×10^{-4}	7.66×10^{-5}	6.69×10^{-4}	1.80×10^{-4}	8.75×10^{-3}	2.80×10^{-3}	1.94×10^{-2}	9.41×10^{-3}
21	93 ~ 94	1	3.68×10^{-5}	3.68×10^{-5}	7.52×10^{-5}	7.52×10^{-5}	7.17×10^{-4}	7.17×10^{-4}	2.16×10^{-3}	2.16×10^{-3}
22	94 ~ 96	2	1.39×10^{-4}	2.74×10^{-5}	2.59×10^{-4}	4.88×10^{-5}	1.95×10^{-3}	3.49×10^{-4}	5.97×10^{-3}	1.16×10^{-3}
23	96 ~ 101	5	2.02×10^{-4}	4.19×10^{-5}	3.49×10^{-4}	6.90×10^{-5}	2.69×10^{-3}	4.81×10^{-4}	9.12×10^{-3}	1.73×10^{-3}
24	115 ~ 122	7	3.92×10^{-4}	2.51×10^{-4}	1.17×10^{-3}	7.32×10^{-4}	3.02×10^{-2}	2.18×10^{-2}	5.09×10^{-2}	4.64×10^{-2}
25	122 ~ 126	4	5.08×10^{-4}	3.20×10^{-4}	1.65×10^{-3}	1.04×10^{-3}	2.36×10^{-2}	1.91×10^{-2}	2.61×10^{-2}	2.46×10^{-2}
26	126 ~ 129	3	1.30×10^{-4}	3.82×10^{-5}	2.64×10^{-4}	7.35×10^{-5}	3.82×10^{-3}	1.08×10^{-3}	1.28×10^{-2}	4.77×10^{-3}
27	129 ~ 132	3	3.43×10^{-4}	9.40×10^{-5}	1.02×10^{-3}	2.72×10^{-4}	1.53×10^{-2}	6.26×10^{-3}	1.97×10^{-2}	1.58×10^{-2}
28	154 ~ 162	8	1.09×10^{-3}	2.97×10^{-4}	3.75×10^{-3}	1.00×10^{-3}	5.03×10^{-2}	2.64×10^{-2}	5.21×10^{-2}	4.42×10^{-2}
29	Hm0 ~ Hm90		4.53×10^{-6}	2.28×10^{-5}	7.21×10^{-6}	3.47×10^{-6}	8.74×10^{-5}	3.46×10^{-5}	6.23×10^{-4}	2.25×10^{-4}

Note: I: The First Stage Development Project
II: The Second Stage Development Project

Table V-2-(1)-4 Probability of Failure of Give-way (P_F)

No.	5,000	10,000	50,000	100,000
1	1.16×10^{-1}	6.62×10^{-2}	7.11×10^{-3}	1.99×10^{-3}
2	0	0	0	0
3	6.52×10^{-2}	3.67×10^{-2}	4.04×10^{-3}	1.25×10^{-3}
4	1.20×10^{-1}	6.74×10^{-2}	8.62×10^{-3}	2.86×10^{-3}
5	0	0	0	0
6	4.19×10^{-2}	2.36×10^{-2}	3.22×10^{-3}	1.12×10^{-3}
7	2.80×10^{-1}	1.61×10^{-1}	2.01×10^{-2}	5.86×10^{-3}
8	3.80×10^{-2}	2.14×10^{-2}	2.74×10^{-3}	9.10×10^{-4}
9	0	0	0	0
10	5.97×10^{-2}	3.37×10^{-2}	4.31×10^{-3}	1.43×10^{-3}
11	2.13×10^{-1}	1.22×10^{-1}	1.40×10^{-2}	3.98×10^{-3}
12	0	0	0	0
13	8.53×10^{-2}	4.52×10^{-2}	5.33×10^{-3}	1.74×10^{-3}
14	0	0	0	0
15	1.15×10^{-1}	5.48×10^{-2}	5.61×10^{-3}	2.37×10^{-3}
16	1.71×10^{-1}	9.12×10^{-2}	1.08×10^{-2}	3.53×10^{-3}
17	1.63×10^{-2}	9.19×10^{-3}	1.01×10^{-3}	3.12×10^{-4}
18	8.37×10^{-2}	4.56×10^{-2}	6.21×10^{-3}	2.02×10^{-3}
19	1.07×10^{-1}	5.01×10^{-2}	4.97×10^{-3}	1.85×10^{-3}
20	1.64×10^{-1}	6.77×10^{-2}	5.18×10^{-3}	2.34×10^{-3}
21	0	0	0	0
22	0	0	0	0
23	5.60×10^{-1}	3.24×10^{-1}	4.20×10^{-2}	1.24×10^{-2}
24	4.61×10^{-1}	1.55×10^{-1}	5.99×10^{-3}	3.56×10^{-3}
25	1.34×10^{-1}	4.13×10^{-1}	2.88×10^{-2}	2.60×10^{-3}
26	6.95×10^{-1}	3.44×10^{-1}	2.37×10^{-2}	7.07×10^{-3}
27	6.62×10^{-2}	2.23×10^{-2}	1.48×10^{-3}	1.15×10^{-3}
28	2.08×10^{-2}	6.05×10^{-3}	4.51×10^{-4}	4.36×10^{-4}
29	1.00×10^{2}	6.28×10^{1}	5.18×10^{0}	7.27×10^{-1}

Table V-2-(1)-5 Grounding Probability (P_G)

	km	km	5,000		10,000		50,000		100,000	
No.	Location	ℓ	I	II	I	II	I	II	I	II
1	19 ~ 31	12	9.07×10^{-5}	1.67×10^{-5}	9.07×10^{-5}	1.59×10^{-5}	9.07×10^{-5}	1.50×10^{-5}	9.07×10^{-5}	1.77×10^{-5}
2	31 ~ 34	3	0	0	0	0	0	0	0	0
3	34 ~ 50	16	1.13×10^{-4}	1.25×10^{-5}	1.13×10^{-4}	1.18×10^{-5}	1.13×10^{-4}	1.13×10^{-5}	1.13×10^{-4}	1.48×10^{-5}
4	64 ~ 71	7	9.07×10^{-5}	1.28×10^{-5}	9.07×10^{-5}	1.22×10^{-5}	9.07×10^{-5}	1.19×10^{-5}	9.07×10^{-5}	1.44×10^{-5}
5	83 ~ 85	2	0	0	0	0	0	0	0	0
6	88 ~ 93	5	2.23×10^{-5}	5.48×10^{-6}	2.27×10^{-5}	5.30×10^{-5}	2.27×10^{-5}	5.33×10^{-6}	2.27×10^{-5}	6.12×10^{-6}
7	132 ~ 134	2	2.23×10^{-5}	1.47×10^{-5}	2.27×10^{-5}	1.45×10^{-5}	2.27×10^{-5}	1.41×10^{-5}	2.27×10^{-5}	1.47×10^{-5}
8	134 ~ 145	11	4.53×10^{-5}	1.09×10^{-5}	4.53×10^{-5}	1.06×10^{-5}	4.53×10^{-5}	1.06×10^{-5}	4.53×10^{-5}	1.26×10^{-5}
9	145 ~ 147	2	0	0	0	0	0	0	0	0
10	147 ~ 154	9	4.53×10^{-5}	1.09×10^{-5}	4.53×10^{-5}	1.06×10^{-5}	4.53×10^{-5}	1.06×10^{-5}	4.53×10^{-5}	1.26×10^{-5}
11	1E ~ 15E	14	2.27×10^{-4}	2.49×10^{-5}	2.27×10^{-4}	2.34×10^{-5}	2.27×10^{-4}	2.11×10^{-5}	2.27×10^{-4}	2.45×10^{-5}
12	15E ~ 19W	2.4	0	0	0	0	0	0	0	0
13	50W ~ 52W	2.0	2.27×10^{-5}	3.36×10^{-6}	2.27×10^{-5}	3.22×10^{-6}	2.27×10^{-5}	3.23×10^{-6}	2.27×10^{-5}	4.00×10^{-6}
14	52W ~ 55W	3.0	0	0	0	0	0	0	0	0
15	55W ~ 59W	4.0	6.80×10^{-5}	9.93×10^{-6}	6.80×10^{-5}	9.51×10^{-6}	6.80×10^{-5}	1.11×10^{-5}	6.80×10^{-5}	1.73×10^{-5}
16	59W ~ 64	5.0	1.13×10^{-4}	1.67×10^{-5}	1.13×10^{-4}	1.60×10^{-5}	1.13×10^{-4}	1.60×10^{-5}	1.13×10^{-4}	1.98×10^{-5}
17	51E ~ 60E	9	1.59×10^{-5}	1.75×10^{-6}	1.59×10^{-5}	1.66×10^{-6}	1.59×10^{-5}	1.59×10^{-6}	1.59×10^{-5}	2.08×10^{-6}
18	71 ~ 75	4	2.27×10^{-5}	6.46×10^{-6}	2.27×10^{-5}	6.25×10^{-6}	2.27×10^{-5}	6.04×10^{-6}	2.27×10^{-5}	6.50×10^{-6}
19	75 ~ 83	8	6.80×10^{-5}	1.90×10^{-5}	6.80×10^{-5}	1.84×10^{-5}	6.80×10^{-5}	1.96×10^{-5}	6.80×10^{-5}	2.47×10^{-5}
20	25 ~ 88	3	4.53×10^{-5}	1.26×10^{-5}	4.53×10^{-5}	1.22×10^{-5}	4.53×10^{-5}	1.45×10^{-5}	4.53×10^{-5}	2.20×10^{-5}
21	93 ~ 94	1	0	0	0	0	0	0	0	0
22	94 ~ 96	2	0	0	0	0	0	0	0	0
23	96 ~ 101	5	1.13×10^{-4}	2.35×10^{-5}	1.13×10^{-4}	2.23×10^{-5}	1.13×10^{-4}	2.02×10^{-5}	1.13×10^{-4}	2.14×10^{-5}
24	115 ~ 122	7	1.81×10^{-4}	1.16×10^{-4}	1.81×10^{-4}	1.14×10^{-4}	1.81×10^{-4}	1.31×10^{-4}	1.81×10^{-4}	1.65×10^{-4}
25	122 ~ 126	4	6.80×10^{-5}	4.29×10^{-5}	6.80×10^{-5}	4.28×10^{-5}	6.80×10^{-5}	5.49×10^{-5}	6.80×10^{-5}	6.41×10^{-5}
26	126 ~ 129	3	9.07×10^{-5}	2.65×10^{-5}	9.07×10^{-5}	2.53×10^{-5}	9.07×10^{-5}	2.56×10^{-5}	9.07×10^{-5}	3.37×10^{-5}
27	129 ~ 132	3	2.27×10^{-5}	6.23×10^{-6}	2.27×10^{-5}	6.05×10^{-6}	2.27×10^{-5}	9.24×10^{-6}	2.27×10^{-5}	1.81×10^{-5}
28	154 ~ 162	8	2.27×10^{-5}	6.17×10^{-6}	2.27×10^{-5}	6.07×10^{-6}	2.27×10^{-5}	1.19×10^{-6}	2.27×10^{-5}	1.93×10^{-5}
29	Hm0 ~ Hm90	9	4.53×10^{-4}	2.28×10^{-4}	4.53×10^{-4}	2.18×10^{-4}	4.53×10^{-4}	1.80×10^{-4}	4.53×10^{-4}	1.64×10^{-4}

Note: I: The First Stage Development Project
II: The Second Stage Development Project

Average probabilities among vessel sizes are listed in Table V-2-(1)-6.

To calculate average grounding probabilities, we used the share of four vessel size categories (0 ~ 10,000 DWT, 10,000 ~ 35,000 DWT, 35,000 ~ 50,000 DWT, 50,000 DWT ~), whose values are 28.3%, 51.0%, 6.3%, 14.4%. And these are calculated using the number of transiting vessels in 1982.

Table V-2-(1)-6 Average Grounding Probabilities

No.	I	II
1	9.07×10^{-5}	1.63×10^{-5}
2	0	0
3	1.13×10^{-4}	1.23×10^{-5}
4	9.07×10^{-5}	1.26×10^{-5}
5	0	0
6	2.27×10^{-5}	5.47×10^{-6}
7	2.27×10^{-5}	1.45×10^{-5}
8	4.53×10^{-5}	1.09×10^{-5}
9	0	0
10	4.53×10^{-5}	1.09×10^{-5}
11	2.27×10^{-4}	2.38×10^{-5}
12	0	0
13	2.27×10^{-5}	3.37×10^{-6}
14	0	0
15	6.80×10^{-5}	1.08×10^{-5}
16	1.13×10^{-4}	1.67×10^{-5}
17	1.59×10^{-5}	1.74×10^{-6}
18	2.27×10^{-5}	6.33×10^{-6}
19	6.80×10^{-5}	1.95×10^{-5}
20	4.53×10^{-5}	1.38×10^{-5}
21	0	0
22	0	0
23	1.13×10^{-4}	2.23×10^{-5}
24	1.81×10^{-4}	1.22×10^{-4}
25	6.80×10^{-5}	4.66×10^{-5}
26	9.07×10^{-5}	2.68×10^{-5}
27	2.27×10^{-5}	8.04×10^{-6}
28	2.27×10^{-5}	8.36×10^{-6}
29	4.53×10^{-4}	2.10×10^{-4}
Total	1.96×10^{-3}	6.25×10^{-4}

Note: I: The First Stage Development Project
II: The Second Stage Development

2) Collision with Dredgers

(i) General Model

During the execution of the Second Stage Development Project, collision with dredgers will contribute to the risk level of the Canal. The probability of this kind of accident is added to the present risk level (phase I).

Collisions with dredgers happen in two ways. One is when grounding vessels collide with dredgers outside buoys. The other is when vessels collide with dredgers which fail to get out of the channel. Such collisions are expressed as a fault tree in Fig. V-2-(1)-7.

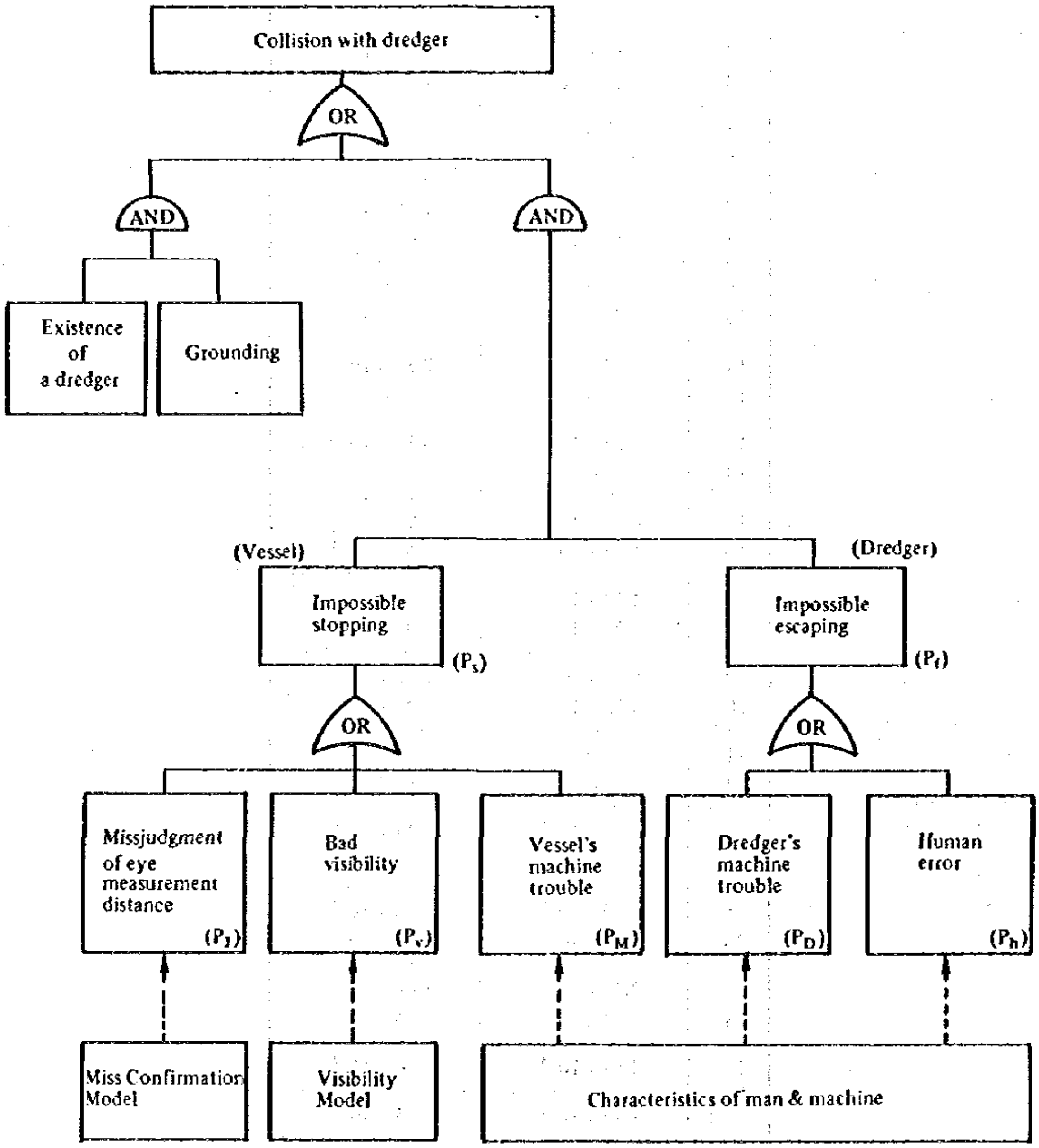


Fig. V-2-(1)-7 Basic Structure of Collision Model under Construction

Based on this tree, a model for such collisions is composed as follows.

$P_C = P_G \times P_E + P_f \times P_s$

P_C : Probability of collision with a dredger
P_G : Probability of grounding
P_E : Probability of the case in which a dredger exists at the site where a vessel grounds
P_f : Probability of failure of getting out of the channel when a vessel approaches
P_s : Probability that the distance from a dredger forward is shorter than her stopping distance after a vessel identifies the dredger.

The cases are simply illustrated in Fig. V-2-(1)-8.

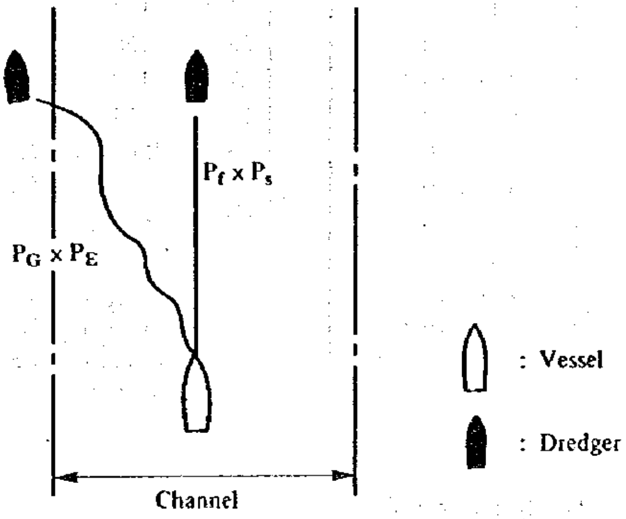


Fig. V-2-(1)-8 Collision with a Dredger

(ii) Probability of Collision with Dredgers

i) Based on Grounding

(a) Probabilities for Grounding (P_G)

Those are already calculated above.

(b) Probability of Dredger's Existence (P_E)

Suppose that m dredgers are arranged ramdomly along the Canal, the probability that a grounding vessel touches the dredger is expressed by the following equation.

$$P_E = \frac{m \times \ell}{162 \text{ (Canal length)} \times 2}$$

ℓ : length of dredger

In this study, by assuming $m = 20$, $\ell = 0.083$ km

P_E is estimated as 5.12×10^{-3}.

(c) Probability of Collision with Dredgers due to Grounding

By multiplying P_G with P_E, the probability due to grounding is estimated as shown in Table V-2-(1)-7.

Table V-2-(1)-7 Probability of Collision with Dredgers Based on Grounding (per transit per kilometer)

No.	Location (Km)	Probability
1	19 – 31	3.84×10^{-8}
2	31 – 34	0
3	34 – 50	3.58×10^{-8}
4	64 – 71	6.61×10^{-8}
5	83 – 85	0
6	88 – 93	2.31×10^{-8}
7	132 – 134	5.84×10^{-8}
8	134 – 145	2.10×10^{-8}
9	145 – 147	0
10	147 – 154	3.28×10^{-8}
11	1E – 15E	8.20×10^{-8}
12	15E – 19E	0
13	50W – 52W	5.84×10^{-8}
14	52W – 55W	0
15	55W – 59W	8.71×10^{-8}
16	59W – 64	1.16×10^{-7}
17	51E – 60E	9.07×10^{-8}

No.	Location (Km)	Probability
18	71 – 75	2.91×10^{-9}
19	75 – 83	4.35×10^{-8}
20	85 – 88	7.84×10^{-8}
21	93 – 94	0
22	94 – 96	0
23	96 – 101	1.16×10^{-7}
24	115 – 122	1.33×10^{-7}
25	122 – 126	8.71×10^{-8}
26	126 – 129	1.55×10^{-7}
27	129 – 132	3.84×10^{-8}
28	154 – 162	1.46×10^{-8}
29	Hm0 – Hm90	2.58×10^{-8}

Note: The probability of collision with dredgers due to grounding is considered negligible at present due to the small number of dredgers currently working in the Canal. The figures in this Table represent the probability of such accidents during construction when a large number of dredgers will be operating.

ii) Based on Dredger's Trouble

The probability of misjudging the distance between a vessel and a dredger when measuring by eye, is estimated as follows.

Table V-2-(1)-8 Probability of Error in Judging Distance (P_j)

Vessel	Stopping Distance (So)	Average Eye Measurement Distance ($\bar{x}$)	$u^* = \frac{So - \bar{x}}{s}$	Probability of Poor Judgement $P(u > u^*) \times P_h$
Up to 11,000 DWT	3.11 km	3.08 km	0.0158	5.080×10^{-4}
Over 11,000 DWT	2.29	2.82	-0.3081	3.783×10^{-4}

Note: For the above calculation, we assume $V_o = 16.5$ km/hr, $H = 20$ m, $P_h = 10^{-3}$ and $CV = 0.61$.

Furthermore, applying the above stopping distance to the cumulative frequency polygon on visibility (shown in Fig. V-2-(1)-21), the probability of poor visibility causing misjudgement of the stopping distance, is obtained as follows.

Table V-2-(1)-9 Probability of Bad Visibility (Pv)

Vessel Size	Stopping Distance So	Probability $P(x < So)$
Up to 11,000 DWT	3.11 km	2.52×10^{-2}
Over 11,000 DWT	2.29	1.58×10^{-2}

The probability of transit vessel's machine trouble (P_M) is equal to the one calculated for collision at two-way passes.

$P_M = 2.98 \times 10^{-5}$ failure/km x 8.1 km/encounter
  $= 2.41 \times 10^{-4}$ failure/encounter

The probability of dredger's machine trouble when escaping (P_D) is assumed as follows:

$PD = 3.30 \times 10^{-4}$ failure/hr x 0.5 hr/escape x 2 escape/day
  $= 3.30 \times 10^{-4}$ failure/day

And, the probability of human error occurring (Ph) is usually the value of 10^{-3}.

Therefore, under the above conditions, we obtain the probability of collision with dredgers based on dredger's trouble (Pc) as shown in Table V-2-(1)-10.

$$Pc = [(Pj + Pv + P_M) \times 20] \times [P_D + 2 \times Ph]$$

Table V-2-(1)-10 Probability of Collision Based on Dredger's Trouble

Vessel Size	Probability
Up to 110,000 DWT	1.21×10^{-3}
Over 110,000 DWT	7.56×10^{-4}

Note: Unit is accidents/transit·vessel

3) Collision Model at Junctions

(i) General Structure

Based on the analysis of traffic characteristics at junctions in the Suez Canal, we propose a collision model at junctions as shown in Fig. V-2-(1)-9.

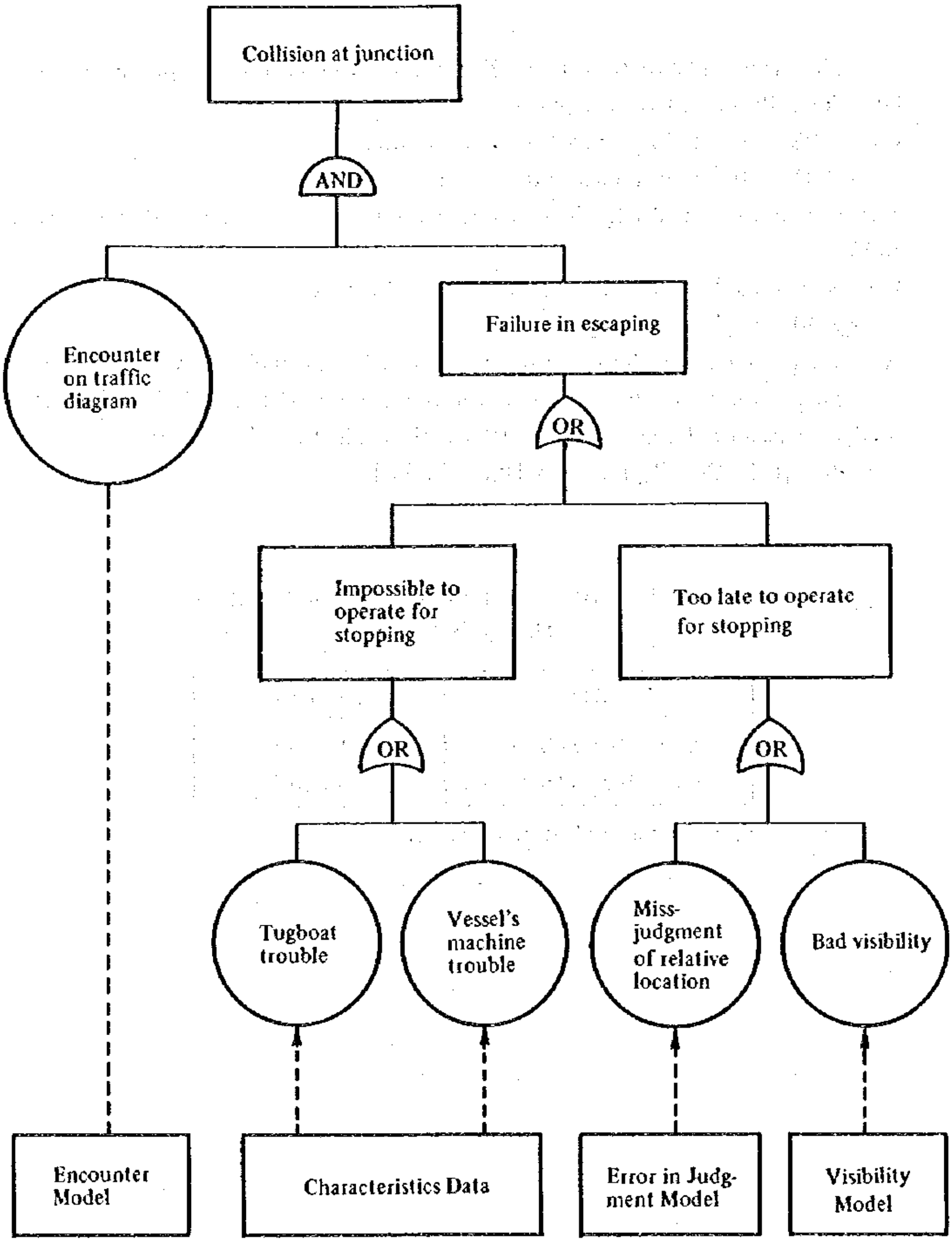


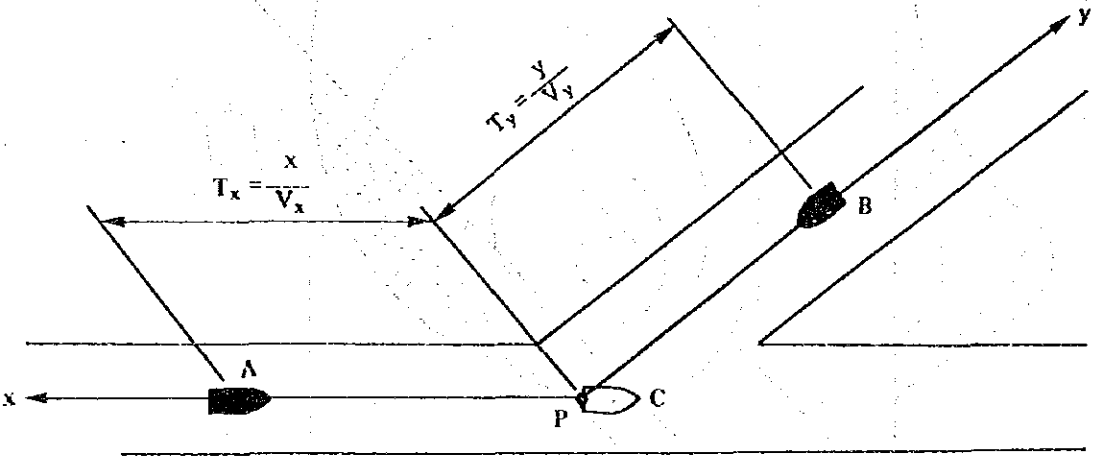
Fig. V-2-(1)-9 General Structure of the Collision Model at Junctions

(ii) Encounter Probability

i) Encounter Model

The encounter model is used to estimate the probability of encounters at junctions.

In this model, "encounters at junction" is defined as is shown in Fig. V-2-(1)-10.



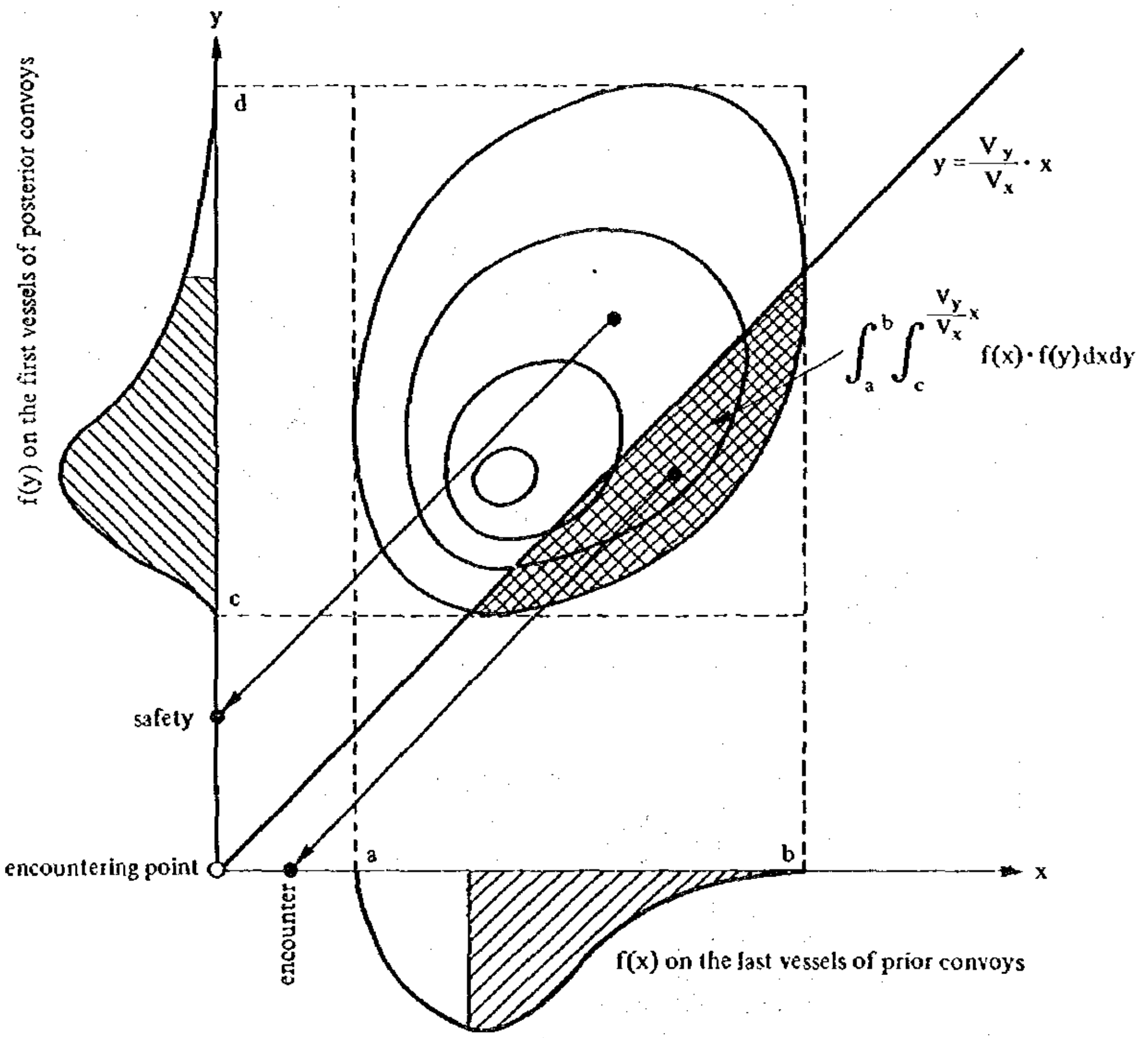
Encounters take place when T_x satisfies the following conditions.

$$T_x > T_y \quad \text{or} \quad y < \frac{V_y}{V_x} x$$

where A : The last vessel of the prior convoy
B : The first vessel of the posterior convoy
P : Encountering point
V_x, V_y : Velocity of vessels A, B
x, y : Distance from the point P
C : Before the last vessel of the prior convoy

Fig. V-2-(1)-10 Encounters at Junctions

Based on the above definition, the fundamental encounter model is shown in Fig. V-2-(1)-11.



where ▩ ; *The field of possibilities for encounter if V_x, V_y are not changed.*
f(x), f(y) : Probability density functions of arrival distribution at junction.

Fig. V-2-(1)-11 Fundamentals of the Encounter Model Structure

ii) Encounter Probability Estimates

The probability that an encounter occurs at each junction P_k can be calculated as follows:

$$P_k = 1 \text{ case/day} \times 2 \text{ vessels/case} \times \frac{1}{N_n} \times \frac{1}{N_s} \times q_k$$

where P_k : Probability of encounter's occurrences at junction k per vessel

N_n : Daily average number of vessels Northbound

N_s : Daily average number of vessels Southbound

q_k : Probability of encounter at junction k per convey

As for qk, Fig. V-2-(1)-12 shows concretely the encounter model for each junction under the following assumptions and SCA's traffic diagram from August 1983.

- Assumption 1

  Arrival distribution at junctions follows a Poisson distribution

- Assumption 2

  Encounters take place at the following three points:

  - Km 61
  - Km 94
  - Km 123

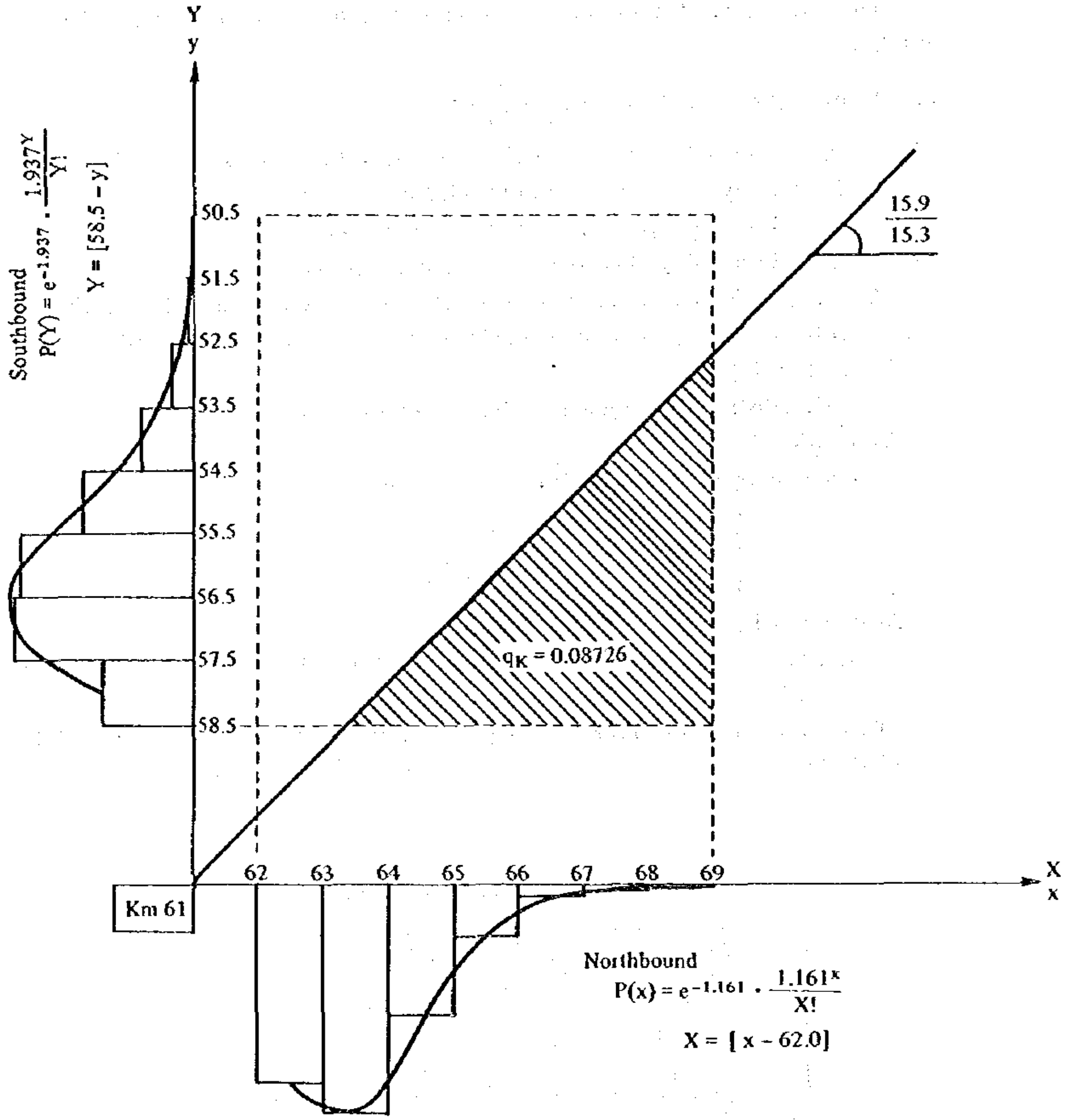
- Assumption 3

  Sections with a probability less than 10^{-3} on the Poisson distribution are ignored.

Then, q_ks, encounter probabilities per convoy are obtained as shown in Table V-2-(1)-11 (1).

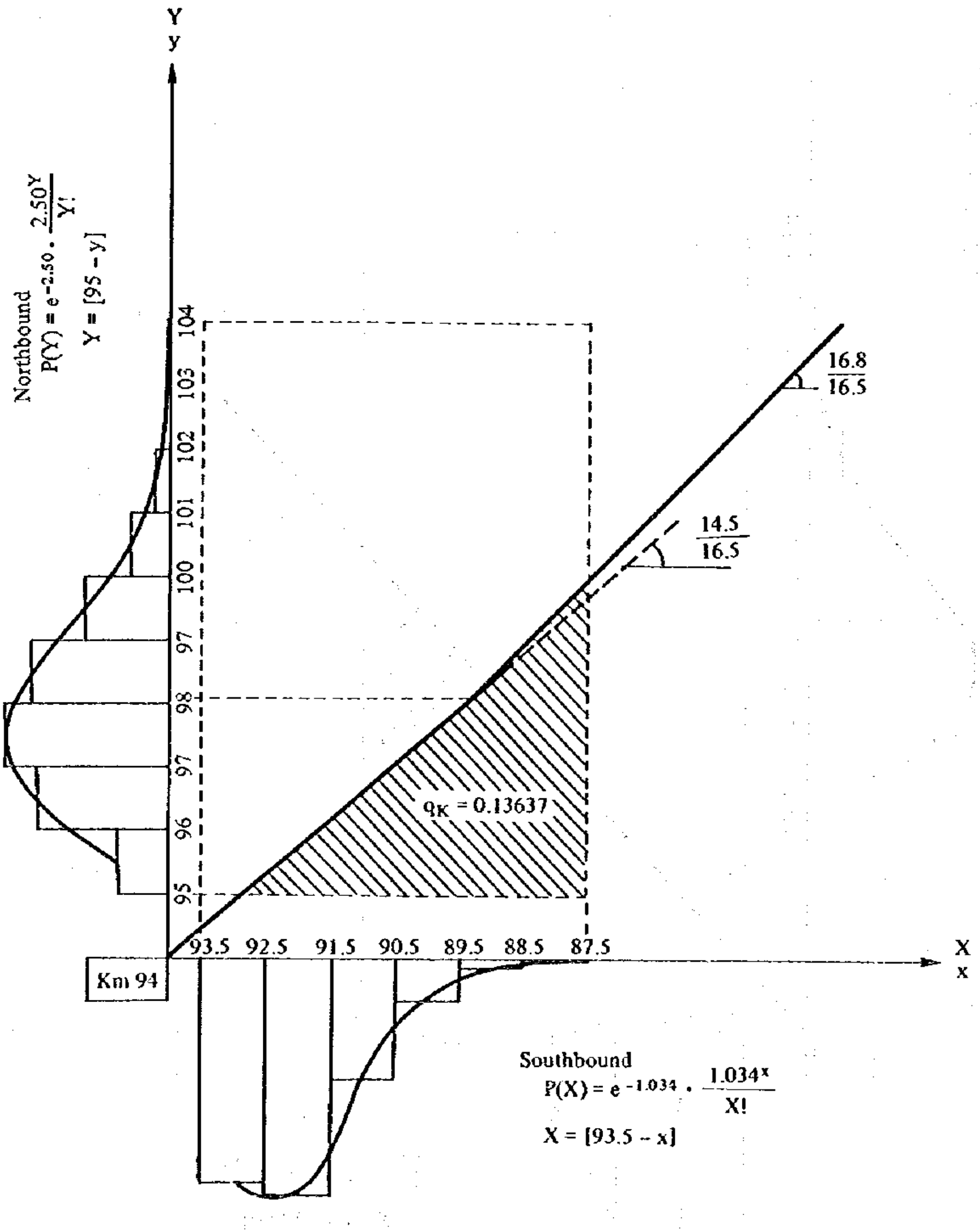
Table V-2-(1)-11 The Value of q_k

Junction k	The Value of q_k
Km 61	0.08726
Km 94	0.13637
Km 123	0.01521



Note: $[Z]$ is the maximum integer less than Z ($Z \geq 0$)

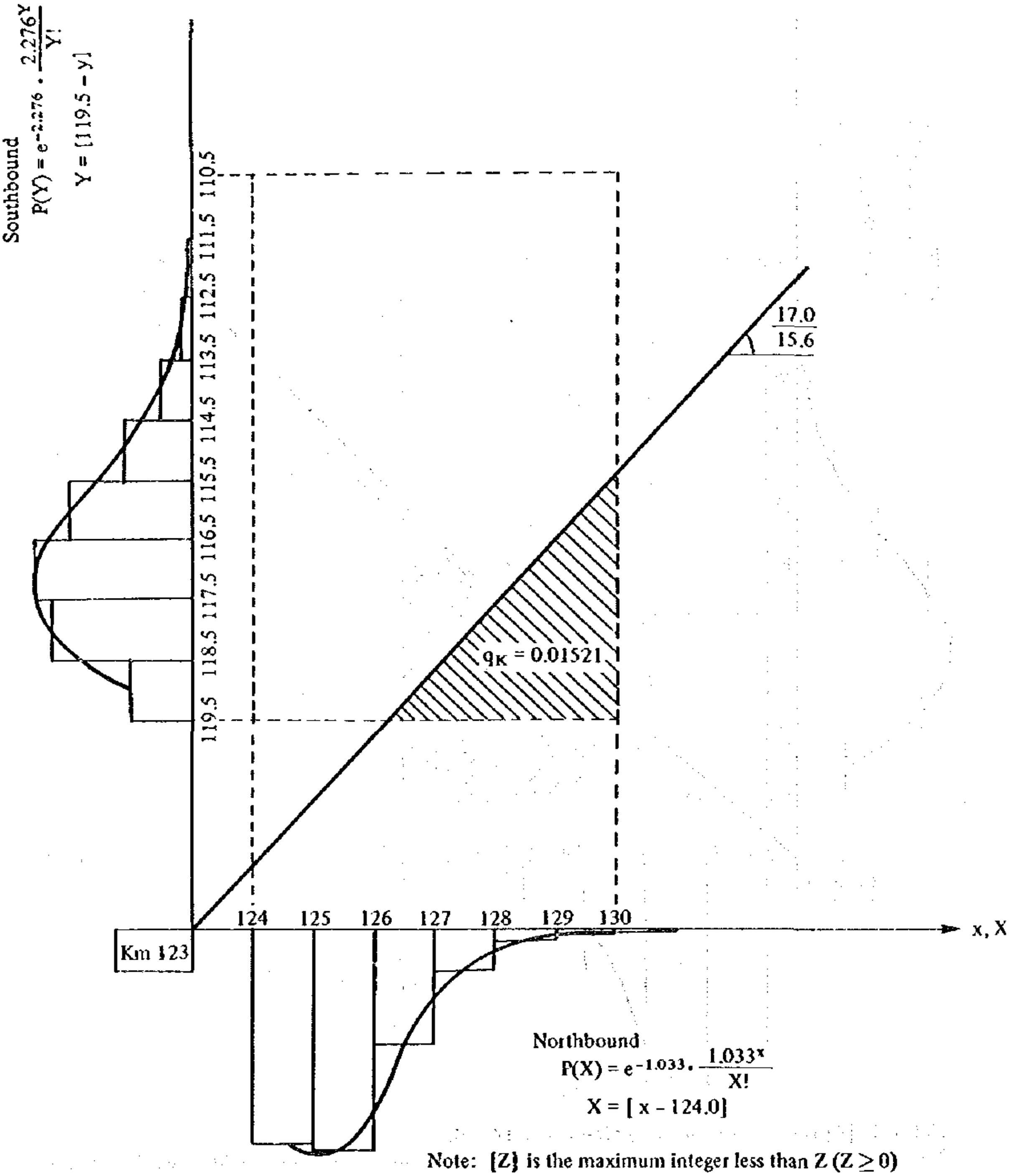
Fig. V-2-(1)-12(1) Encounter Model at Km 61



Note (1): [Z] is the maximum integer less than Z ($Z \geq 0$)

Note (2): Gradient of the vessel's trace bends from 16.8/16.5 to 14.5/16.5 due to the speed change of the posterior convoy at Km 98. (From the SCA's diagram)

Fig. V-2-(1)-12(2) Encounter Model at Km 94



Note: [Z] is the maximum integer less than Z ($Z \geq 0$)

Fig. V-2-(1)-12(3) Encounter Model at Km 123

The values N_n and N_s in the equation for P_k are given as follows:

Table V-2-(1)-12 Number of Vessels per Day by Direction

Stage (Typical Year)	Total Number of Vessels per Year	Number of Vessels per Day	
		(Northbound) Nn	(Southbound) Ns
The First Stage Development Project (1982)	22,545	34.8	27.0
During Construction (1990)	27,000	41.6	32.3
The Second Stage Development Project (2000)	28,000	43.2	33.5

Note: The percentage of traffic in each direction during construction and after construction is completed is assumed to be equal to the present percentage.

Inputting all the variables into the equation, we calculate the probability of encounter occurring at each junction as shown below in Table V-2-(1)-13.

Table V-2-(1)-13 Probability of Encounter Occurring per Transit Vessel at Junctions

Encountering Point / Stage	Km 61	Km 94	Km 123
The First Stage Development Project	1.857×10^{-4}	2.903×10^{-4}	3.238×10^{-5}
Under Construction	1.298×10^{-4}	2.030×10^{-4}	2.264×10^{-5}
The Second Stage Development Project	1.206×10^{-4}	1.885×10^{-4}	2.102×10^{-5}

(iii) Probability of Failure in Escaping

i) General Structure

Cases and causes of failure in escaping are shown in Fig. V-2-(1)-13 and Table V-2-(1)-14.

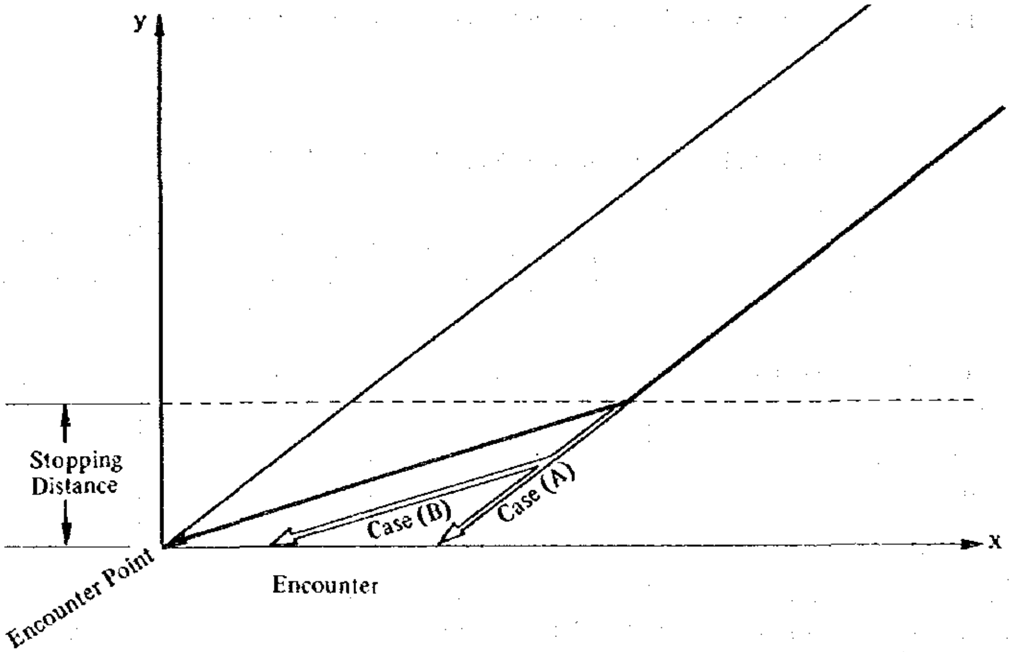


Fig. V-2-(1)-13 Causes of Failure in Escaping

Table V-2-(1)-14 Causes of Failure in Escaping

Case	Causes
A	Impossible to stop – Tugboat trouble – Vessel's machine trouble
B	Too late to stop – Misjudgement of relative location – Bad visibility

ii) Stopping Distance in the Canal

According to Rules of Navigation, emergency stopping operations in the Canal take place as follows:

- Vessels less than 110,000 DWT:
  Stopping operation by the main propulsive engine.
- Vessels more than 110,000 DWT:
  Stopping operation by using the main propulsive engine and the assistance of tugboats of low speed.

In this report, emergency stopping distance are calculated using the following formulas:

(a) Stopping Distance for Vessels less than 110,000 DWT

We take into consideration the impact of shallow water to Cap. Topley's equation for deep and open water as follows:

$$So \fallingdotseq c\,(1-\alpha)\,Vo/41.58$$

where So : Stopping distance (miles)
c : The coefficients of reduction (See Table V-2-(1)-15)
Vo : Velocity of vessel (knots)
α : Ratio of reduced velocity (See Table V-2-(1)-16)

Table V-2-(1)-15 Coefficients of Reduction

DWT	c (min)	DWT	c (min)	DWT	c (min)
1,000	1	~36,000	8	~120,000	15
~3,000	2	~45,000	9	~136,000	16
~6,000	3	~55,000	10	~152,000	17
~10,000	4	~66,000	11	~171,000	18
~15,000	5	~78,000	12	~190,000	19
~21,000	6	~91,000	13	~210,000	20
~28,000	7	~105,000	14		

The ratio of velocity reduction, α, is a function of the vessel's velocity V, the depth of channel H, wet cross section Am and acceleration of gravity g. Values of α are shown in Table V-2-(1)-16. These values reflect the shallow waters effect by the affect of H.

Fig. V-2-(1)-14 shows an example of calculations of the stopping distance So.

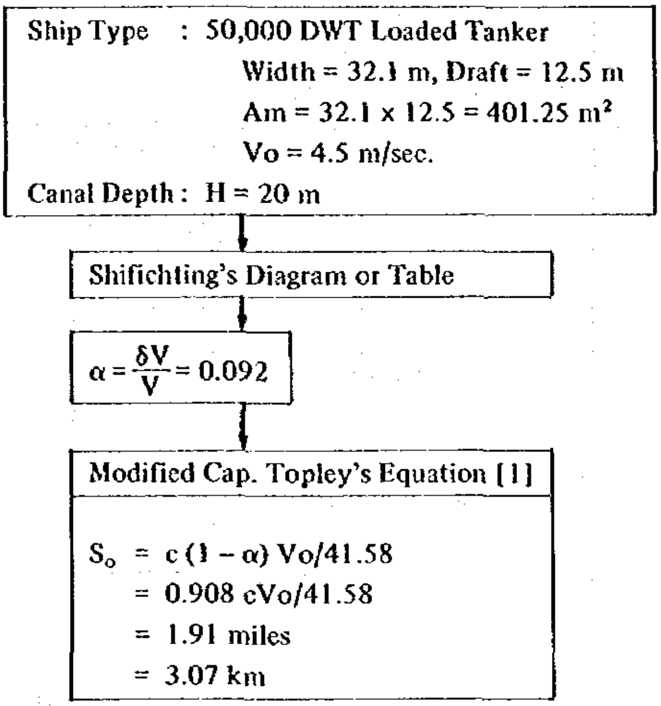
Table V-2-(1)-16 Values of $\delta V/V$ (α) x 100 (%) (Shilichting's Diagram)

V^2/gH	$\sqrt{Am/H}$												
	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
0.10		1.1	1.8	3.0	4.2	5.7	7.4	9.2	10.9	12.8	14.7	16.7	18.0
0.30		1.4	3.0	3.9	5.4	7.0	8.0	10.5	12.4	14.0	15.5	17.2	18.0
0.40	1.4	2.2	3.4	4.7	6.1	7.7	9.3	11.3	13.0	14.8	16.4	17.7	18.8
0.45	1.9	2.5	3.6	5.0	6.7	8.5	9.9	11.8	13.4	15.2	16.9	18.2	19.4
0.50	2.5	3.3	4.3	5.7	7.0	8.7	10.5	12.3	14.1	15.7	17.4	18.7	20.0
0.55	3.0	3.8	5.0	6.4	8.1	9.0	11.0	12.9	14.8	16.4	18.0	19.3	20.8
0.60	4.1	4.9	6.0	7.1	8.6	10.2	12.0	13.6	15.4	17.1	18.7	20.0	21.0
0.65	4.9	6.1	7.0	8.4	9.9	11.2	13.0	14.5	16.4	18.0	19.6	21.0	22.5
0.70	6.3	7.1	8.0	9.3	10.9	12.3	14.0	15.6	17.4	19.0	20.5	22.1	23.4
0.75	7.0	8.0	9.0	10.5	12.0	13.4	15.0	16.2	18.4	20.0	21.5	22.9	24.2
0.80	8.8	9.4	10.5	11.7	13.0	14.4	16.0	17.8	19.4	21.0	22.4	23.8	25.0
0.85	10.0	10.8	11.6	12.7	14.0	15.5	17.0	18.9	20.5	22.0	23.3	24.7	26.1
0.90	11.0	12.0	12.9	14.0	15.2	16.9	18.3	20.0	21.5	22.9	24.2	25.6	27.1
0.95	12.4	13.0	14.0	15.1	16.4	18.0	19.3	21.0	22.4	23.9	25.1	26.6	28.1
1.00	13.5	14.1	15.1	16.1	17.6	19.0	20.3	22.0	23.4	24.9	26.1	27.7	29.2
1.05	14.6	15.3	16.4	17.4	18.8	20.2	21.4	23.0	24.5	26.0	27.2	28.7	30.3
1.10	15.7	16.5	17.6	18.7	20.0	21.3	22.5	24.0	25.5	27.0	28.2	29.6	31.3
1.15	17.0	17.8	18.8	19.8	21.0	22.2	23.6	25.0	26.6	28.0	29.2	30.7	32.3
1.20	18.3	19.0	19.9	20.8	22.0	23.1	24.7	26.0	27.6	28.9	30.2	31.7	33.2
1.25	19.4	20.0	20.9	21.9	23.0	24.3	25.8	27.1	28.6	29.9	31.2	32.7	34.2
1.30	20.4	21.0	22.0	22.9	24.0	25.4	26.8	28.1	29.5	30.9	32.1	33.6	35.1
1.35	21.4	22.0	22.9	23.8	25.0	26.4	27.8	29.0	30.4	31.7	33.0	34.4	36.0
1.40	22.4	23.0	23.9	24.8	26.0	27.4	28.7	30.0	31.3	32.6	34.0	35.3	37.0
1.45	23.4	24.0	24.9	25.8	27.0	28.3	29.5	30.8	31.9	33.4	34.8	36.2	37.8
1.50	24.4	25.5	25.9	26.8	28.0	29.2	30.4	31.7	33.0	34.2	35.6	37.0	38.6

Note: V: m/se Am: m^2 H: m g: 9.81 m/sec.

Source: H. Lackenby, "The effect of shallow water on ship speed", The Ship Builder and Marine Engine-Builder, Sept. 1963

[Example]



Ship Type : 50,000 DWT Loaded Tanker

Width = 32.1 m, Draft = 12.5 m

$A_m = 32.1 \times 12.5 = 401.25\ m^2$

Vo = 4.5 m/sec.

Canal Depth : H = 20 m

Shifichting's Diagram or Table

$\alpha = \frac{\delta V}{V} = 0.092$

Modified Cap. Topley's Equation [1]

$$\begin{aligned} S_o &= c(1-\alpha)\,Vo/41.58 \\ &= 0.908\ cVo/41.58 \\ &= 1.91 \text{ miles} \\ &= 3.07 \text{ km} \end{aligned}$$

Fig. V-2-(1)-14 Example of Calculation of Stopping Distance

(b) Stopping Distance for Vessels more than 110,000 DWT

In this case, the stopping operation is composed of two steps. The first operation is the same as for vessels less than 110,000 DWT using the modified Cap. Topley's equation. The step is continued for t until the tug operation starts. After the interval t, tugboats start to be effective in addition to propulsive stopping. These stops are illustrated in Fig. V-2-(1)-15.

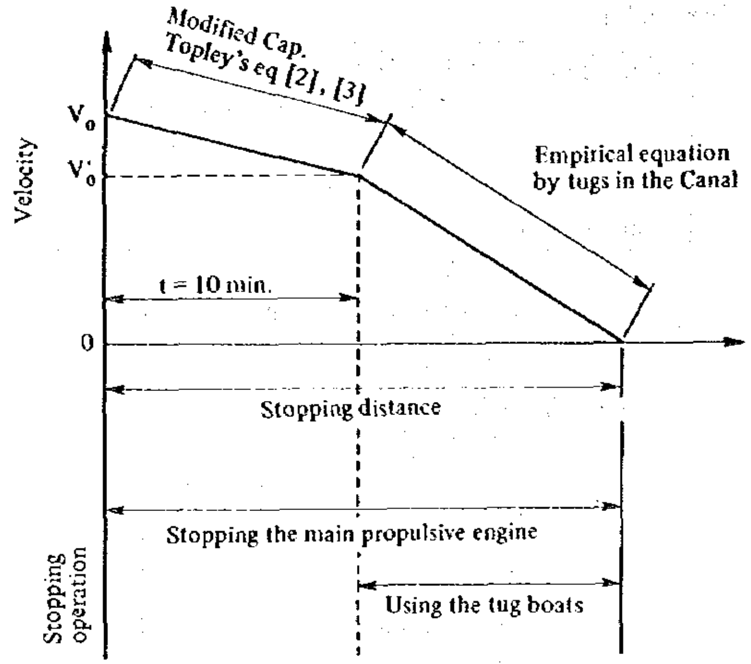


Fig. V-2-(1)-15 Stopping Process for Vessels over 110,000 DWT

The first stage of stopping needs the following distance, and the vessel speed comes up to Vo'.

$$So = c\,(1 - \alpha)\,Vo\,(1 - 2^{-\frac{t}{c}})\,/\,41.58$$

$$Vo' = (1 - \alpha)\,Vo\,2^{-\frac{t}{c}})$$

Where So : Advanced distance for t (miles)
Vo' : Velocity after t (Kt)
c : Coefficient of reduction (min)
(see Table V-2-(1)-16)
α : Ratio of reduced velocity (See Table V-2-(1)-16)
Vo : Velocity of vessel (Kt)
t : Time (min)

As for the second stage of stopping, the necessary distance So', in addition, is expressed by the following equation, obtained by regression analysis using field stopping trial data.

$$So' = 344.78\,Vo' - 225.88$$

where So' : Stopping distance (m)
Vo' : Velocity of vessel at the end of first stage of stopping operation (m/sec)

Data: the relations between entry speed (Vo') and stopping distance (So) are shown in Table V-2-(1)-17 and Fig. V-2-(1)-16.

An example of the calculation of the second stage of stopping distance and total stopping distance (So + So') is shown in Fig. V-2-(1)-17.

Table V-2-(1)-17 Summary of Field Stopping Trials

Run No.	Entry Speed m/sec	Stopping Distance meters	Current m/sec	Relative Wind m/sec	Tug Pull Max (average) tonnes	Method
VESSEL "LOADED" 11.6 m DRAUGHT						
1	3.5	1069	0.5 stern	12 015°	22/28 (14/14)	2 Duckpellers on quarter wires (35 m)
2	2.9	575	1.1 head	Nil	29/23 (18/11)	as above (30 m)
3	3.5	1260	0.6 stern	8 360°	29/26 (14/11)	as above
4	2.6	975	1.1 head	Nil	21 (10)	1 Duckpeller on bridle (30 m leg)
5	7.6	1255	0.5 stern	11 015°	22 (11)	as above
VESSEL IN BALLAST 8.2 m MEAN DRAUGHT						
6	3.5	890	0.7 head	3 315°	19/26 (6/8)	2 Duckpellers on quarter wires (30 m)
7	3.8	1050	0.7 head	3 315°	18/30 (8/9)	as above
8	3.7	985	0.5 stern	3 045°	14/28 (6/9)	as above
9	3.2	440	0.3 head	4 360°	14 (8)	1 Duckpeller on bridle (35 m leg)
10	2.7	540	0.3 head	4 360°	13 (9)	as above but wider angle
11	4.8	1400	0.9 stern	3 360°	30 (10)	as above
12	3.5	1050	0.7 stern	3 360°	25 (12)	as above
13	1.7	400	0.1 stern	2 290°	30 (17)	as above

Source: A.A. Ammar and R.H. le F. Ashburner, "Study on Stopping and Safety Operation in Suez Canal".

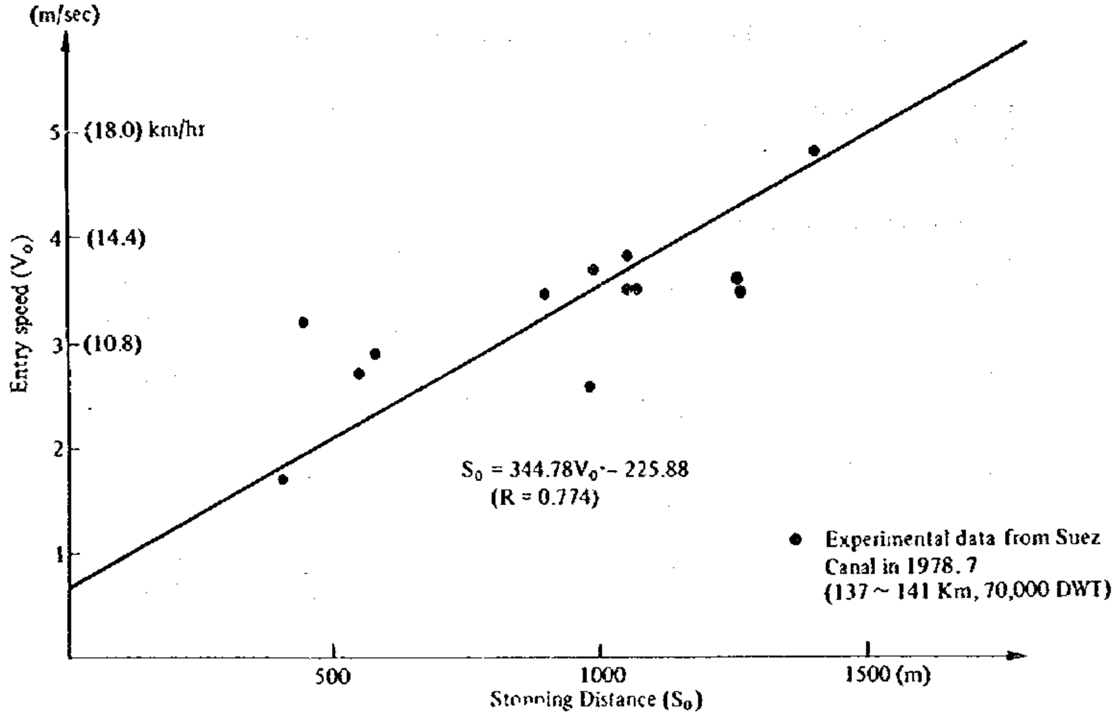


Fig. V-2-(1)-16 Relation between Entry Speed and Stopping Distance

[Example]

Ship Type: 150,000 DWT Loaded Tanker
Width = 44.2 m, Draft = 17.9 m
Am = 44.2 x 17.9 = 791.18 m^2
Vo = 4.7 m/sec
Canal Depth: H = 20 m

Modified Cap. Topley's Equation [2], [3]

$$S_O = C\,(1-\alpha)\,Vo\,(1-2^{-\frac{t}{c}})/41.58$$
$$= 17 \times 0.833 \times 9.18 \times 0.335/41.58 = 1.68 \text{ km}$$
$$Vo' = (1-\alpha)\,Vo\,2^{-\frac{t}{c}}$$
$$= 0.833 \times 9.14 \times 0.665 = 5.06 \text{ kt} = 2.6 \text{ m/sec}$$

Empirical Equation in Suez Canal

$$So' = 344.78\ Vo' - 225.88$$
$$= 344.78 \times 2.6 - 225.88 = 671 \text{ m}$$

Total Stopping Distance S_T

$$S_T = So + So' = 2.4 \text{ km}$$

Fig. V-2-(1)-17 Example of Calculation of Stopping Distance for Vessels over 110,000 DWT

(c) Calculation Results of Stopping Distance

By using the above procedure, stopping distance at each junction is calculated as follows.

Table V-2-(1)-18 Stopping Distance

Location	Entry Vessel Speed (Vo)	Canal (H)	Stopping Distance (So)	
			Up to 110,000 DWT	Over 110,000 DWT
Km 61	15.9 Km/hr	20.2	3.0 Km	2.2 Km
Km 94	15.8	20.2	3.0	2.2
Km 123	17.0	20.0	3.2	2.4

Note:
1. The above Vo are obtained by processing the actual traffic diagram from August 1983.
2. The standard vessel characteristics used for Am are as follows: Up to 110,000 DWT, Width = 32.1 m, Draft (Loaded) = 12.5 m, assuming that 50,000 DWT tanker is representative. Over 110,000 DWT, width = 44.2 m, Draft (Loaded) = 17.9 m, assuming that 150,000 DWT tanker is representative.

iii) Human Error

One cause of not being able to stop in time is operators' handling errors. A sample of human error data for various operations is reported in table V-2-(1)-19.

Generally, the probability of human error occurrence during an operation is 10^{-3} *failures/operation. In this report, we use the above value as the probability of human* error occurrence per operation in traffic.

Table V-2-(1)-19 Human Error Data

No.	Job Factor	Probability of Failure/Operation
1	Reading a technical manual	8.2×10^{-3}
2	Reading the graduations of an ammeter	5.5×10^{-3}
3	Checking a loose bolt	4.5×10^{-3}
4	Checking the level of rusting	3.7×10^{-3}
5	Writing down data	3.4×10^{-3}
6	Confirming the location of a switch	1.7×10^{-3}
7	Closing a hand valve	1.7×10^{-3}
8	Opening a hand valve	1.5×10^{-3}
9	Confirming the installing and removing of factors	1.2×10^{-3}

Source: The Table of Reliability of Job Factors by Hammer

iv) Machine Trouble

Machine trouble is another cause for ineffective stopping operation. Probability of machine trouble in vessels' stopping action is obtained as follows.

First, the data of vessel machine trouble is shown below.

Table V-2-(1)-20 Data of Vessel Machine Trouble

Type of Vessel	No. of* Vessel	Average Vessealage	Voyage Time Hours/Year Vessel	Time of Stops of Main Engine	No. of Stops of Main Engine
Container	2,232	10.08	5,307	6.37	2.45
Bulk	3,859	8.67	6,307	6.42	3.11
Tanker	3,602	6.33	6,509	4.96	1.45
G.C.	8,910	7.50	4,686	3.27	1.26
Others	3,439	10.42	7,018	5.08	2.17
Total	22,042	8.23	5,694	4.69	1.88

Source: Bulletin of Marine Engineering Society in Japan, Vol. 18 No. 19, Nov. 1983.

Note (*): The mixture which was used to calculate the weighted average of machine trouble is replaced by the actual pattern of the Canal transits.

Therefore, the probability of machine trouble occurrence is generally 3.30×10^{-4} failure/hr.

$$\frac{1.88 \text{ failure/year vessel}}{5694 \text{ hr/year vessel}} = 3.30 \times 10^{-4} \text{ failure/hr}$$

Then, since the average time required for transit in the Suez Canal is 14.6 hr/transit, the probability of vessel machine trouble occurrence in the Canal P is obtained as follows:

$$P = 3.30 \times 10^{-4} \text{ failure/hr} \times 14.6 \text{ hr/transit}$$
$$= 4.82 \times 10^{-3} \text{ failure/transit}$$

Further, P per 1 Km is

$$P = 2.98 \times 10^{-5} \text{ failure/km}$$

Therefore we can obtain the probability of vessel machine trouble in stopping distance Pso by using the following equation as shown in Table V-2-(1)-21.

$$Pso = P \text{ failure/km} \times So \text{ km}$$

(So : stopping distance)

Table V-2-(1)-21 Probability of Vessel Machine Trouble in Stopping Distance at Junctions

Location	Up to 110,000 DWT	Over 110,000 DWT
Km 61	8.94×10^{-5}	6.60×10^{-5}
Km 94	8.94×10^{-5}	6.60×10^{-5}
Km 123	9.60×10^{-5}	7.20×10^{-5}

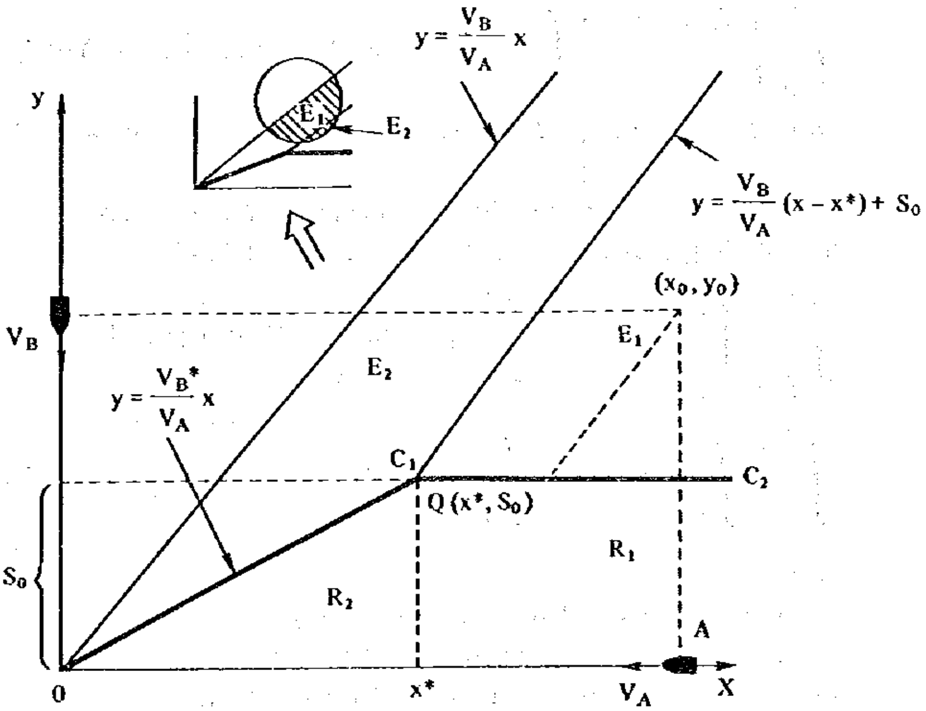
v) Probability of Misjudgment

(a) Misjudgment of Distance

The probability of making an error when confirming the distance from the vessel encountering point at junctions is equal to the probability of human error occurrence as above.

Making a mistake of judgment when measuring the relative distance between vessels by eye delays the operation of escaping.

The thick line O-C_1-C_2 in Fig. V-2-(1)-18 is a set of critical positions where a vessels has to start stopping action. These are the last possible points to begin stopping and still avoid collision.



S_0: Critical Distance for Stopping of Ship B

x^*: $(= \frac{V_A}{V_B^*} S_0)$: Distance between ship A and Point P that ship A can avoid collision with ship B when ship B starts breaking at Point Q.

V_B^* : Ship B'_A speed in stopping action.

(x_0, y_0): The coordinates of the last transit A of a Northbound Convoy and the first transit B of a Southbound Convoy when the second to last transit of the Northbound Convoy sails at Point P.

Fig. V-2-(1)-18 Critical Line for Stopping

If the initial positions of both vessels, denoted by (xo, yo) are in the region E_1, posterior vessel B has to start stopping when she reaches a position a given stopping distance (So) from the junction. On the other hand, if the initial positions are in region E_2, the line OC_1, representing the path of both vessels when vessel B is in the process of stopping with reduced speed, is the limit for stopping.

In both cases, when the operator misunderstands the distance, that is, when the operator thinks the vessels are farther apart than they actually are, it becomes too late to stop to escape collision.

As for the case of initial position E_1, the probability is expressed as follows:

$$\text{Pc1} = \text{Prob. } [\text{Ym} \geq \text{So} \mid y = \text{So}, (\text{xo}, \text{yo}) \subset E_1]$$

$$= \int_{x^*}^{\infty} \int_{\text{So}}^{\frac{\text{VB}}{\text{VA}}(\text{xo}-x^*)+\text{So}} \int_{\text{So}}^{\infty} \phi_{ym}\ (\text{ym} \mid y = \text{So}, (\text{xo}, \text{yo}) \subset E_1)\, \text{dym}\phi_{\text{XoYo}}\ (\text{Xo}, \text{Yo})\ \text{dyodxo}$$

$$= \int_{x^*}^{\infty} \int_{\text{So}}^{\frac{\text{VB}}{\text{VA}}(\text{xo}-x^*)+\text{So}} \int_{\text{So}}^{\infty} \phi_{ym}\ (\text{ym} \mid y = \text{So})\, dy_m \phi_{\text{XoYo}}\ (\text{Xo}, \text{Yo})\ \text{dyodXo}$$

where, ϕ_{ym} (ym | y): p.d.f. of measured distance, ym, by ship when the real distance is y.

In the case of initial position E_2, the probability is expressed as follows:

$$\text{Pc2} = \text{Prob. } [\text{ym} \geq y^{**} \mid y = y^{**}, x = x^{**}, (\text{to}, \text{yo}) \subset E_2]$$

$$= \int_{\frac{\text{VA}}{\text{VB}^*}\text{So}}^{\infty} \int_{\frac{\text{VB}}{\text{VA}}(\text{xo}-x^*)+\text{So}}^{\frac{\text{VB}}{\text{VA}}\text{xo}} \left[\int_{y^{**}}^{\infty} \phi_{ym}\ (\text{ym} \mid y = y^{**}, (\text{xo}, \text{yo}) \subset E_1)\, \text{dym} \right] \phi_{\text{XoYo}}\ (\text{XoYo})\ \text{dYodXo}$$

$$+ \int_{0}^{\frac{\text{VA}}{\text{VB}^*}\text{So}} \int_{\frac{\text{VB}^*}{\text{VA}}\text{xo}}^{\frac{\text{VB}}{\text{VA}}\text{xo}} \left[\int_{y^{**}}^{\infty} \phi_{ym}\ (\text{ym} \mid y = y^{**})\, \text{dym} \right] \phi_{\text{XoYo}}\ (\text{Xo}, \text{Yo})\ \text{dyodXo}$$

where

$x^{**} = (\text{VB} \cdot \text{xo} - \text{VA} \cdot \text{yo}) / (\text{VB} - \text{VB}^*)$

$y^{**} = \text{VB}^* (\text{VBxo} - \text{VAyo}) / \text{VA} (\text{VB} - \text{VB}^*)$

So, misoperating probability Ps is calculated as follows:

$\text{Ps} = \text{Pc1} + \text{Pc2}$

As for the misjudgment function ϕ_{ym} (ym | y),
we can apply the following model to the Canal.
The model of errors in measurement by eye is as follows:

- Average of measured distance ym (x)

  $\log X = 11.218 + 8.290 \log R - 1.168 (\log R)^2$

  where R: actual distance (m)

- Coefficient of Variance CV

  $CV = 0.61$

The parameters of the model are composed using the data presented in Fig. V-2-(1)-19

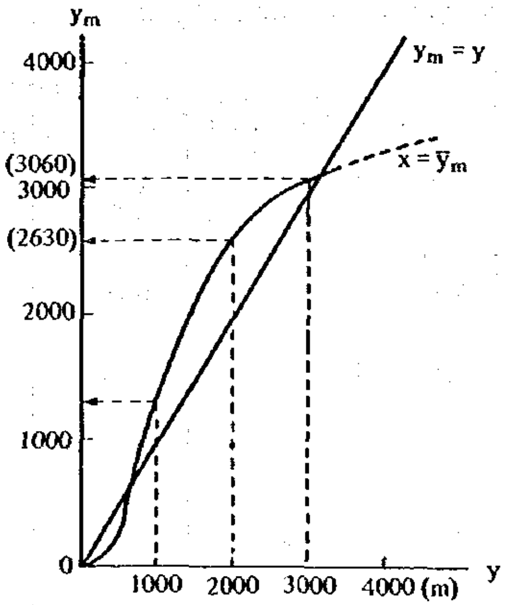


Fig. V-2-(1)-19 Eye Measurement Data (Japanese)

Finally, based on the fault tree shown in Fig. II-2-(1)-9 the probability of the occurrence of delayed stopping operation causing failure to escape, P, can be calculated using the following equation.

$P = P_h \times Ps$

where, P_h : Probability of error judging the distance from vessel to encountering point at junctions

Ps : Probability of error judging of the distance between vessels at junctions

(b) Estimating the Probability of Misjudgment

The estimated results which were obtained using the model described above are shown in Table V-2-(1)-22

Table V-2-(1)-22 Probability of Misjudgment

Location	Vessel Size	Stopping Distance So	Average Eye Measurement Distance of So $\bar{x}$	Probability of Misjudgement		
				Distance between Vessels Ps	Distance from Vessel to Encountering Point Ph	Ps x Ph
Km 61	Up to 110,000 DWT	Km 3.0	Km 3.1	0.4801	1.0×10^{-3}	4.801×10^{-4}
	Over 110,000 DWT	2.2	2.8	0.3632		3.632×10^{-4}
Km 94	Up to 110,000 DWT	3.0	3.1	0.4801		4.801×10^{-4}
	Over 110,000 DWT	2.2	2.8	0.3632		3.632×10^{-4}
Km 123	Up to 110,000 DWT	3.2	3.1	0.5199		5.199×10^{-4}
	Over 110,000 DWT	2.4	2.9	0.3897		3.897×10^{-4}

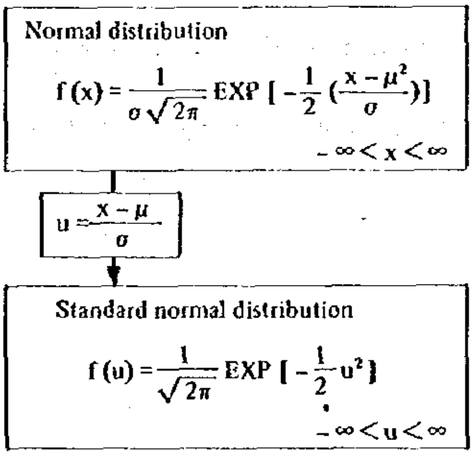
Note: Ps in the above table is calculated as follows:

1st step: Calculate $u^* = \frac{So - \bar{x}}{s}$

Where s is the standard deviation ($S = \bar{x} \times CV$)

2nd step: Determine probability $P(u < u^*)$ by using the probability table of standard normal distribution

Reference:



Normal distribution

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \text{EXP}\left[-\frac{1}{2}\left(\frac{x-\mu^2}{\sigma}\right)\right]$$

$$-\infty < x < \infty$$

$$u = \frac{x - \mu}{\sigma}$$

Standard normal distribution

$$f(u) = \frac{1}{\sqrt{2\pi}} \text{EXP}\left[-\frac{1}{2}u^2\right]$$

$$-\infty < u < \infty$$

vi) Visibility

(a) Visibility Model

When the actual visibility (ℓ_R) is less than the necessary visibility (ℓv), it is too late to stop and avoid collision. As Fig. V-2-(1)-20 shows, ℓv differs by velocity, stopping distance and vessel's initial position. Critical visibility (ℓcv) is the minimum necessary visibility [ℓv] to avoid collision at each point.

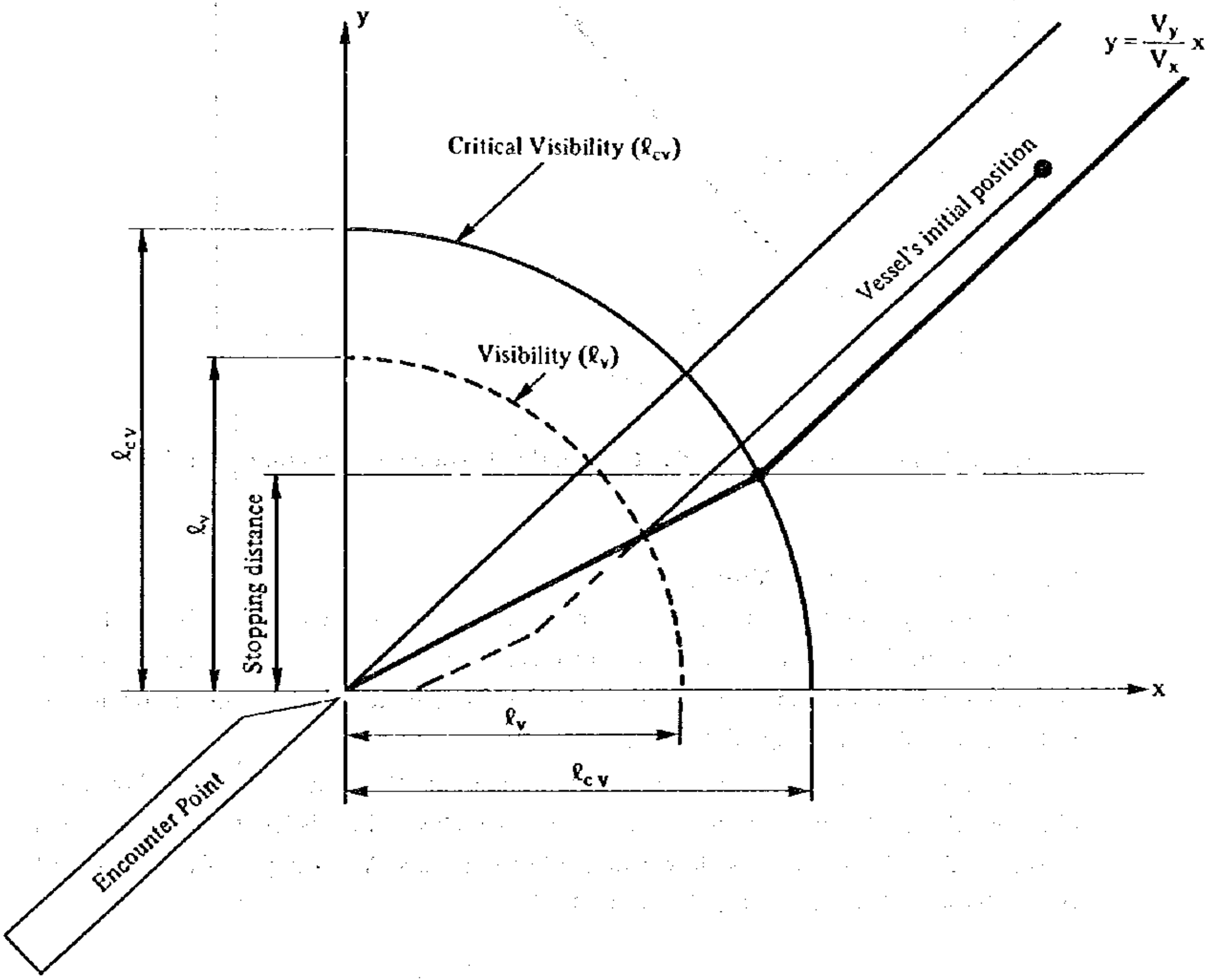


Fig. V-2-(1)-20 Principle of Marginal Visibility

The probability of $\ell_R < \ell_V$ is given from the cumulative frequency polygon at each location.

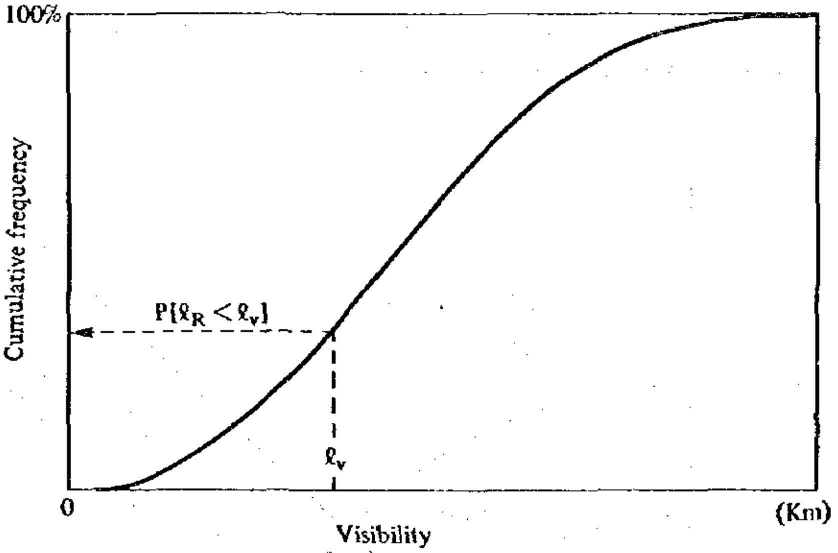


Fig. V-2-(1)-21 How to Use the Cumulative Frequency Polygon on Visibility

(b) Estimation for Poor Visibility

Necessary visibilities at each junction are obtained as shown in Fig. V-2-(1)-12.

Since the data on visibility in the Canal is not adequate, we assume that the cumulative frequency polygon at points Km 61, Km 94, and Km 123 is similar to the one at Ismailia as shown in Fig. V-2-(1)-21.

Therefore, using data which were obtained in the way described above, we obtained the probability of the occurrences in which visibility is less than the marginal causing failure in escaping as shown in Table V-2-(1)-23. An example of calculation of the probability is shown in Fig. V-2-(1)-23.

Table V-2-(1)-23 Probability of Bad Visibility

Location		Up to 110,000 DWT	Over 110,000 DWT
Km 61	Objective Convoy	Southbound	
	Probability	1.883×10^{-3}	1.258×10^{-3}
Km 94	Objective Convoy	Northbound	
	Probability	1.758×10^{-3}	9.791×10^{-4}
Km 123	Objective Convoy	Southbound	
	Probability	1.572×10^{-4}	1.858×10^{-4}

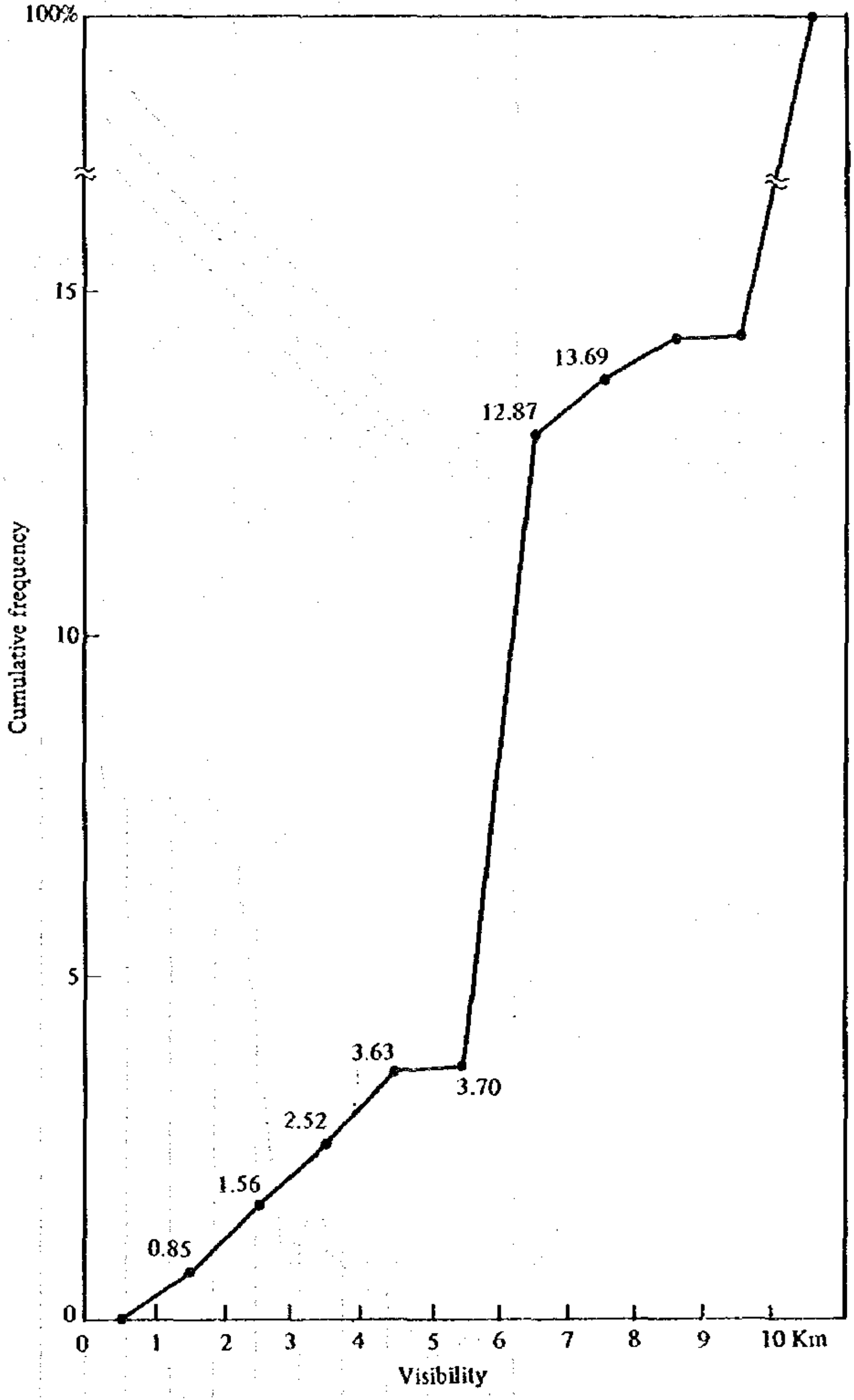


Fig. V-2-(1)-22 Cumulative Frequency Polygon on Visibility at Ismailia

$$
\begin{aligned}
P_v &= \sum_i q_i \cdot q_c \\
&= 0.00036 \times 0.0370 \\
&\quad + 0.00255 \times 0.0363 \\
&\quad + 0.01230 \times 0.0065 \\
&= 1.858 \times 10^{-4}
\end{aligned}
$$

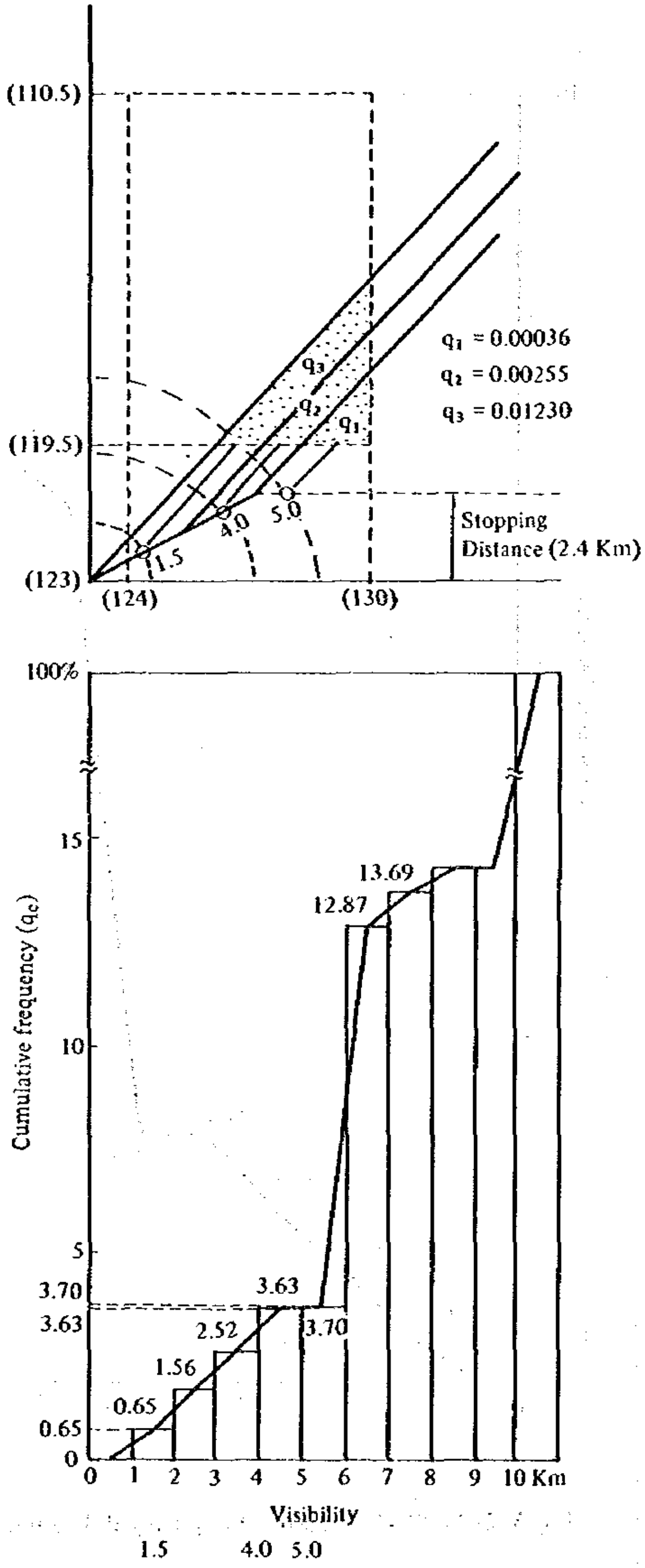


Fig. V-2-(1)-23 Example of Calculation of Collision due to Poor Visibility

(iii) Estimation Results of Probabilities of Collision at Junctions

Based on the principle of Fault Tree Analysis, we can obtain the overall probability of collisions occurring at junctions in the Suez Canal as shown in Table V-2-(1)-24.

Table V-2-(1)-24 Overall Probability of Collisions at Junctions

Location Stage	Km 61	Km 94	Km 123
The First Stage Development Project	4.554×10^{-7} 3.255×10^{-7}	6.756×10^{-7} 4.331×10^{-7}	2.503×10^{-8} 2.330×10^{-8}
Under Construction (1990)	3.183×10^{-7} 2.275×10^{-7}	4.725×10^{-7} 3.029×10^{-7}	1.750×10^{-8} 1.629×10^{-8}
The Second Stage Development Project (2000)	2.957×10^{-7} 2.114×10^{-7}	4.387×10^{-7} 2.812×10^{-7}	1.625×10^{-8} 1.512×10^{-8}

Note: Upper row: Up to 110,000 DWT
Low row: Over 110,000 DWT

(iv) Sensitivity Analysis

We suppose that important and manageable factors for reducing the probability of collisions at junctions are the velocity of vessels and the arrival point of the posterior convoy.

Therefore, we shall analyze the sensitivity for reducing the probability of collisions through these two factors by considering the following two case studies.

[ALT. CASE 1]

The vessel speed of the posterior convoy Vy is reduced to 0.8 x Vy near the junction as is shown in Fig. V-2-(1)-24.

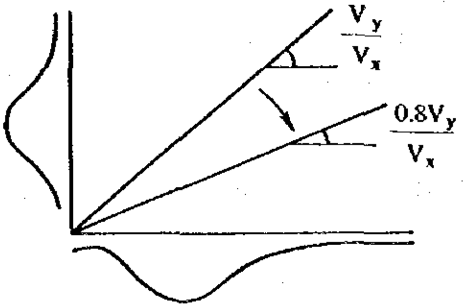


Fig. V-2-(1)-24 Change in Speed Vy

Figs. V-2-(1)-26(1) ~ (3) illustrate the reduction of risk owing to the change in the speed of the posterior convoy.

[ALT. CASE 2]

The arrival point of the posterior convoy at the junction is shifted 2 km backward as shown in the following Fig. V-2-(1)-25.

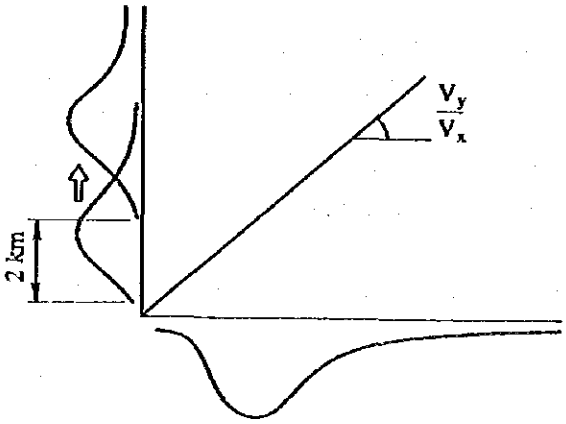
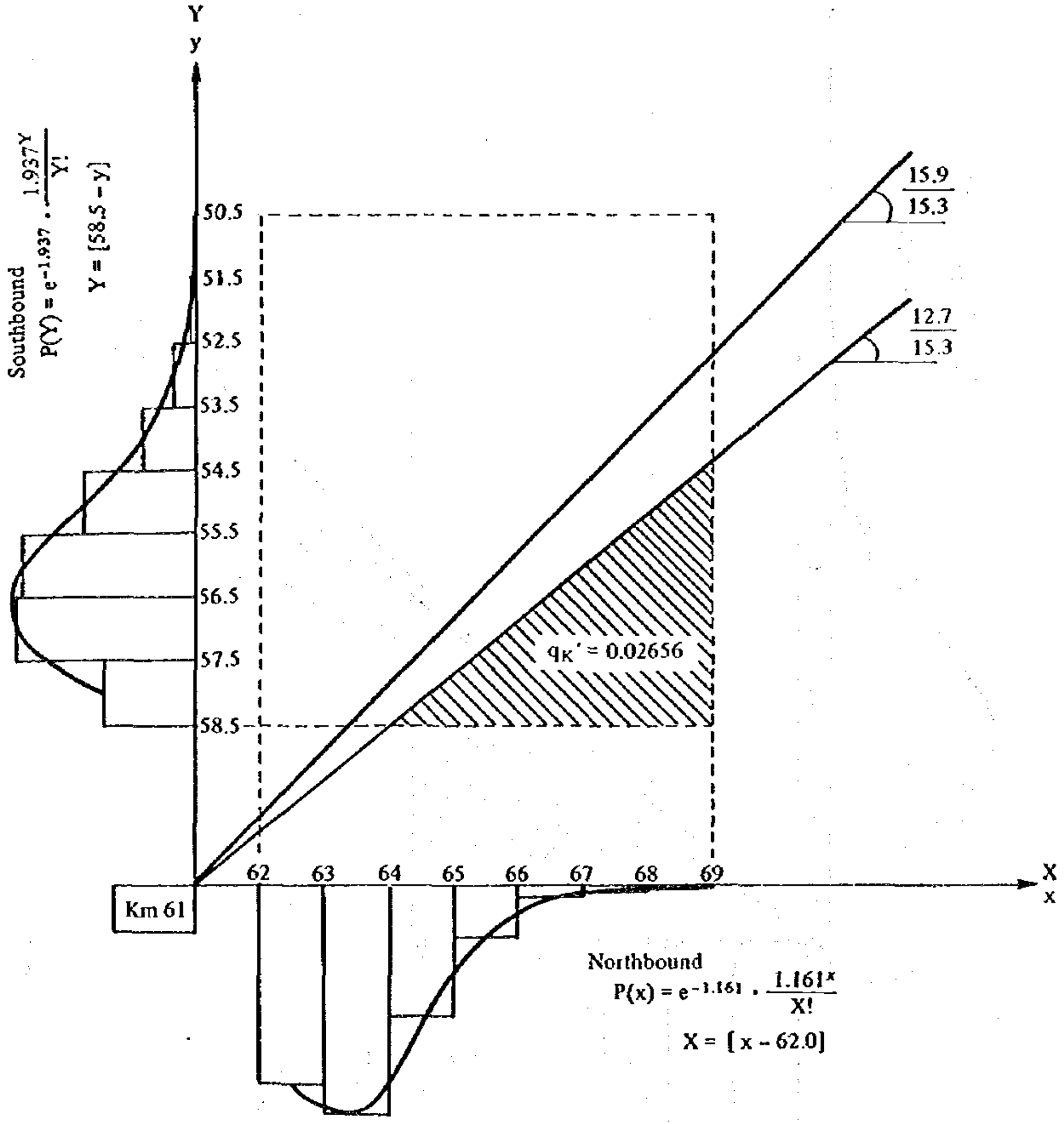


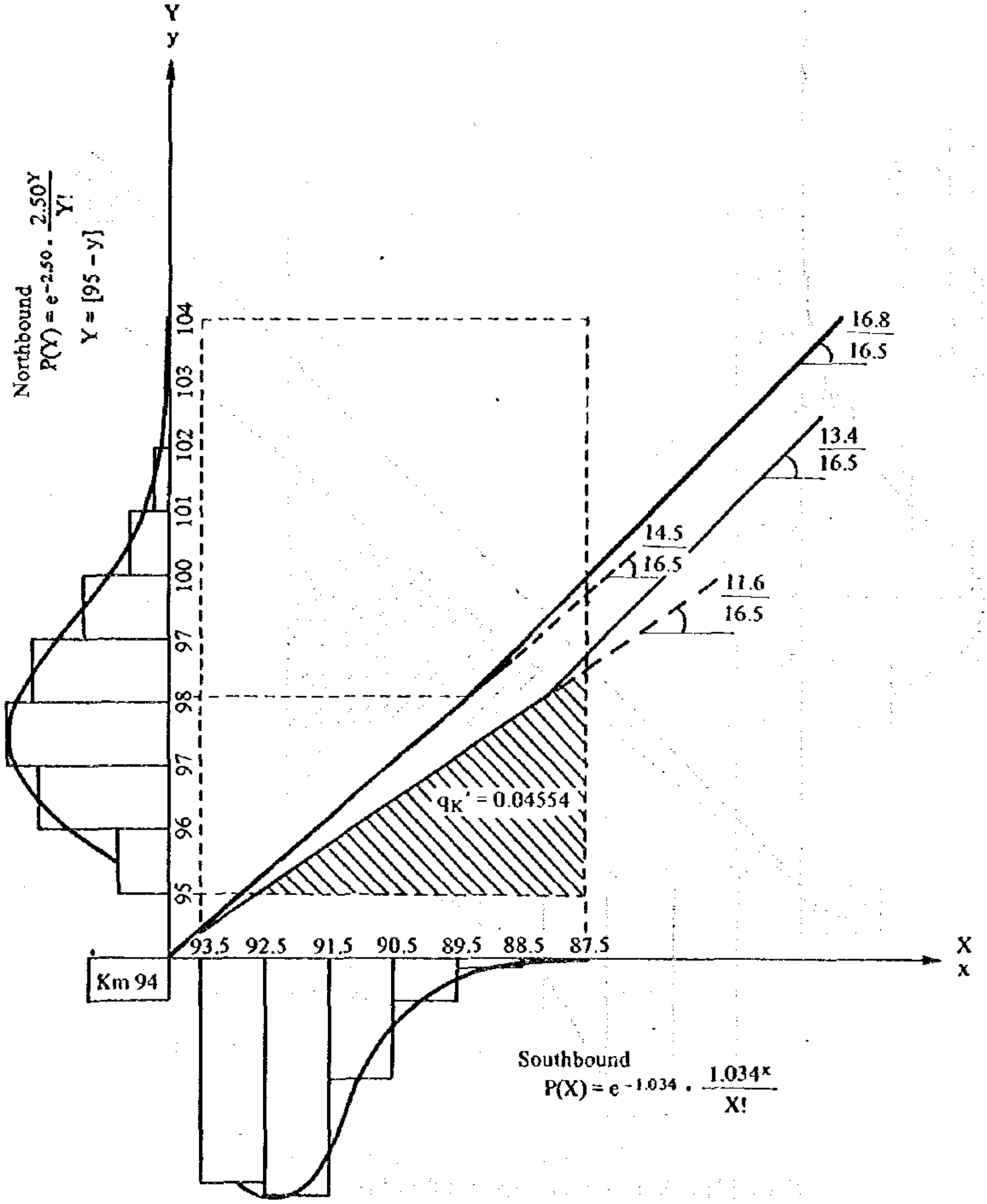
Fig. V-2-(1)-25 Change in Arrival Point

Figs. V-2-(1)-27(1) ~ (3) illustrate the reduction of risk owing to this shift.



Note: [Z] is the maximum integer less than Z ($Z \geq 0$)

Fig. V-2-(1)-26(1) Encounter Model at Km 61



Note: Gradient of the vessel's trace bends from 16.8/16.5 (14.5/16.5) to 14.5/16.5 (11.6/16.5) due to the speed change of the posterior convoy at Km 98. (From the SCA's diagram)

Fig. V-2-(1)-26(2) Encounter Model at Km 94

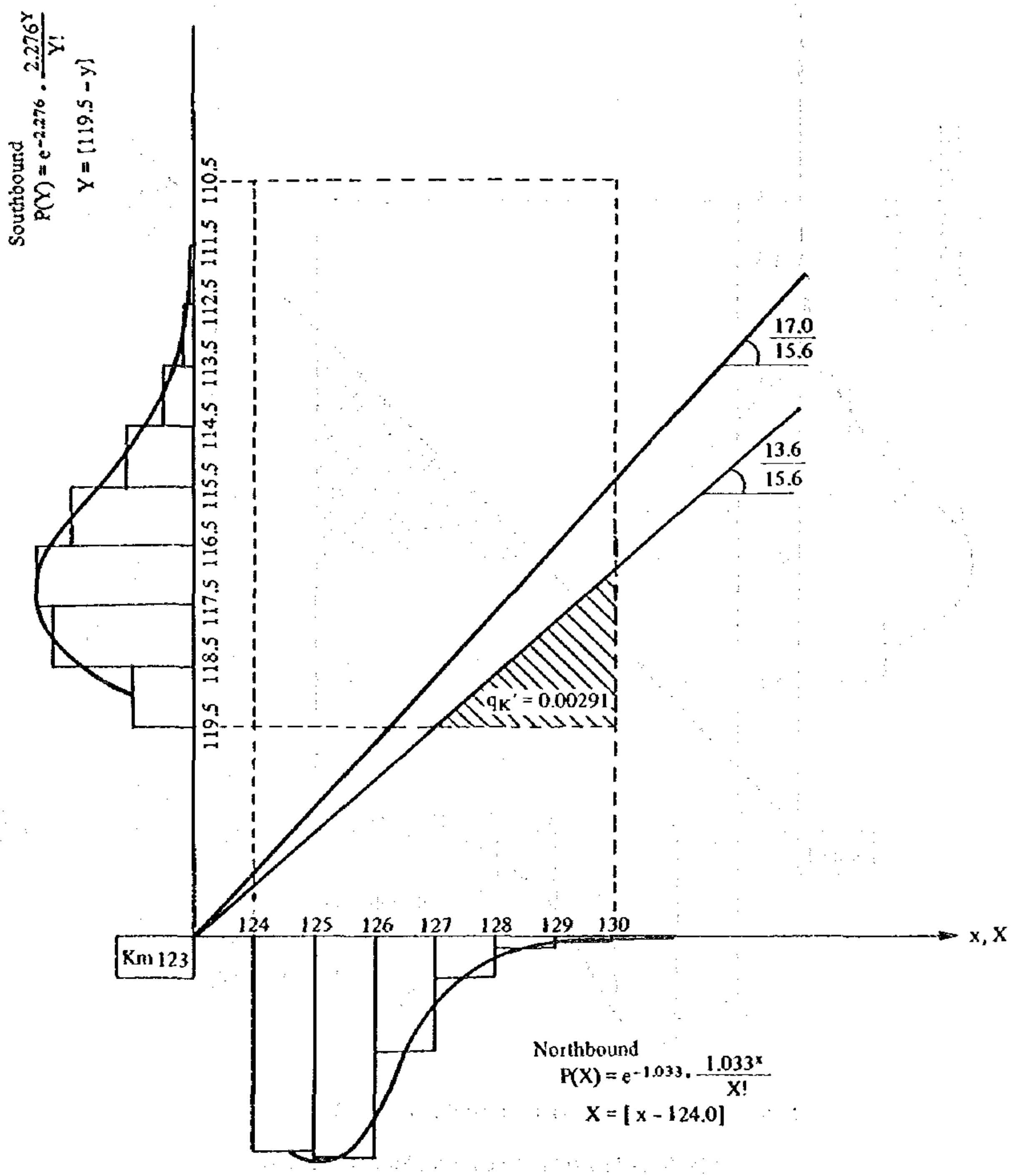
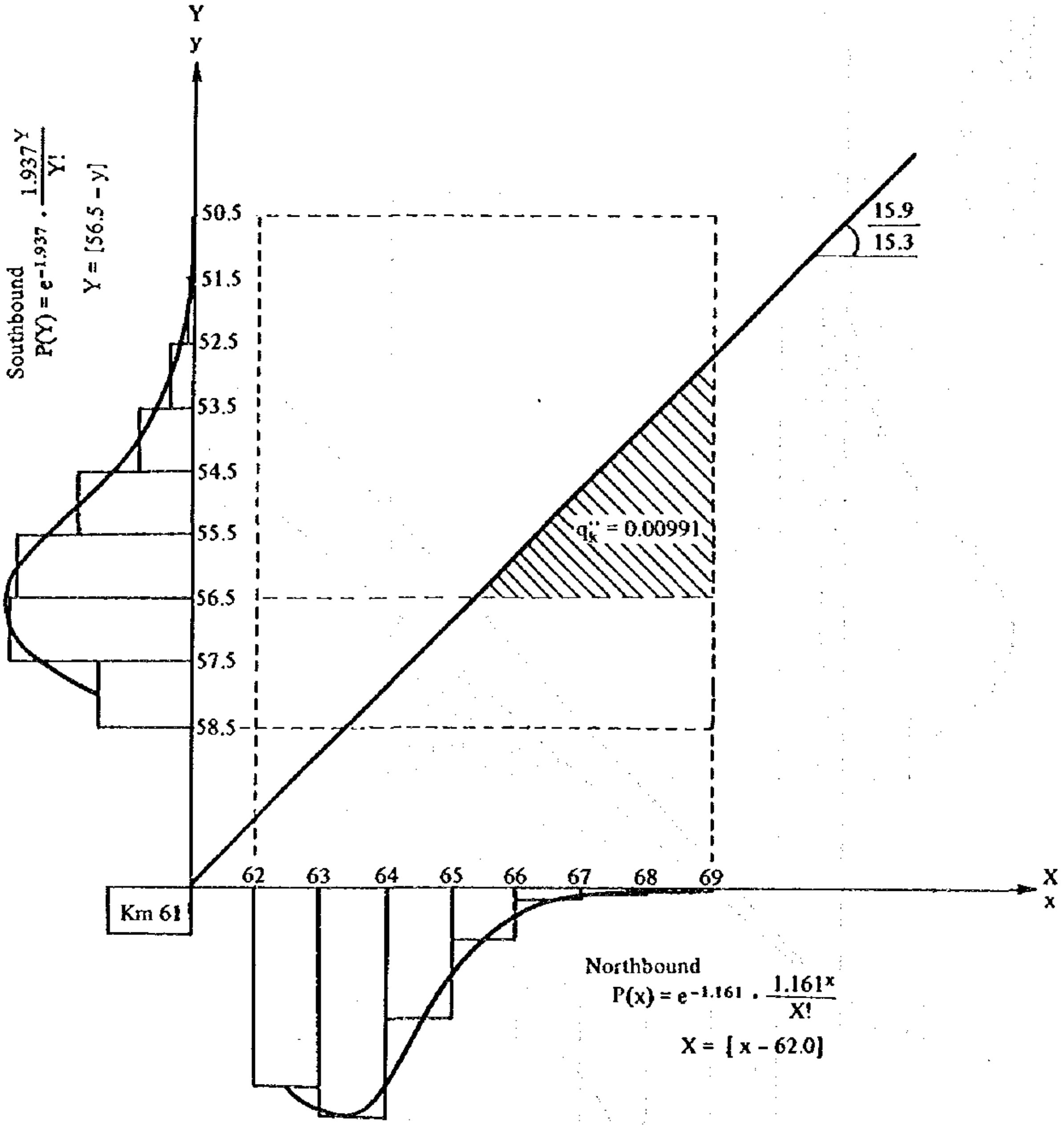
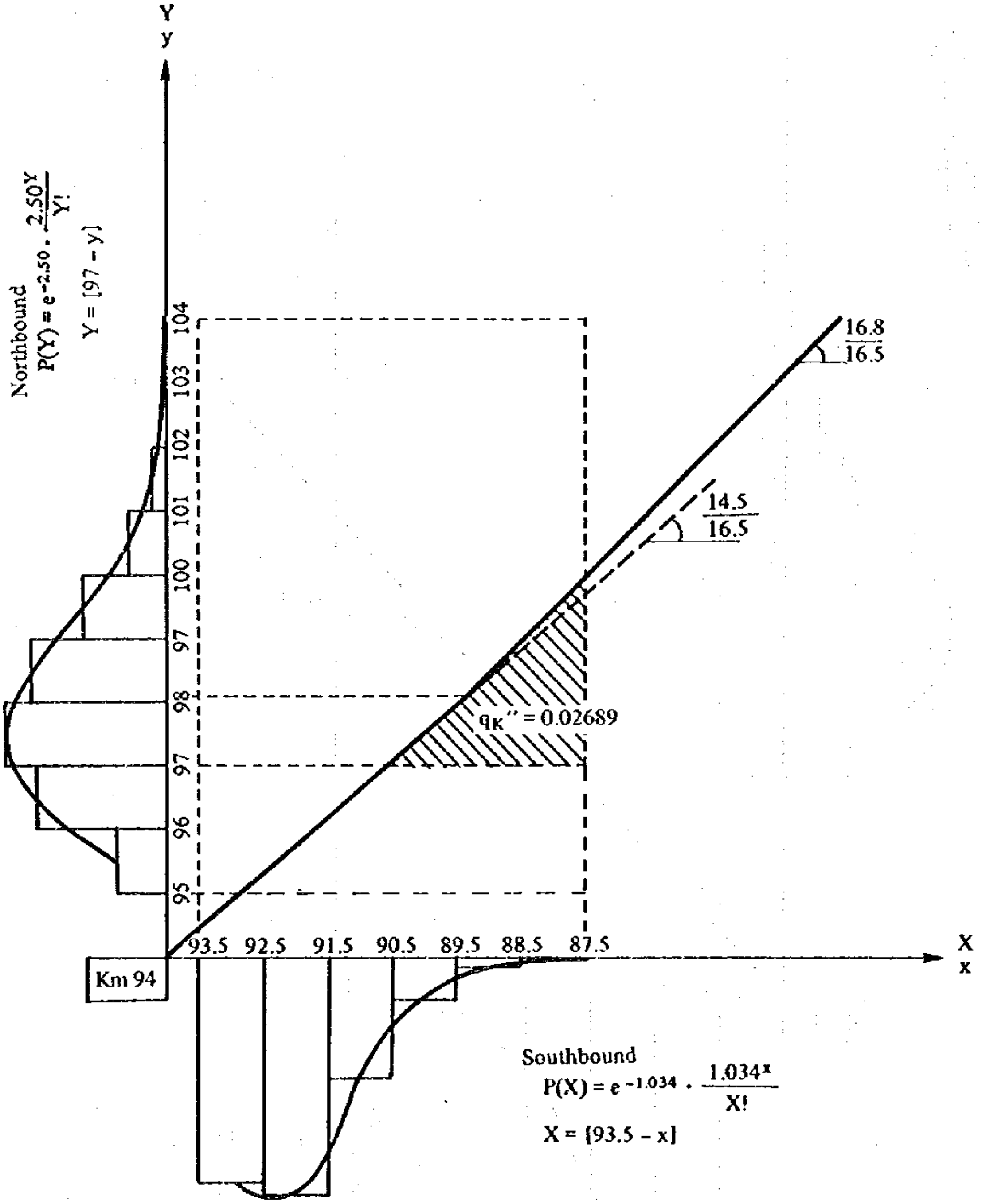


Fig. V-2-(1)-26(3) Encounter Model at Km 123



Note: [Z] is the maximum integer less than Z (Z ≥ 0)

Fig. V-2-(1)-27(1) Encounter Model at Km 61



Note: Gradient of the vessel's trace bends from 16.8/16.5 to 14.5/16.5 due to the speed change of the posterior convoy at Km 98. (From the SCA's diagram)

Fig. V-2-(1)-27(2) Encounter Model at Km 94

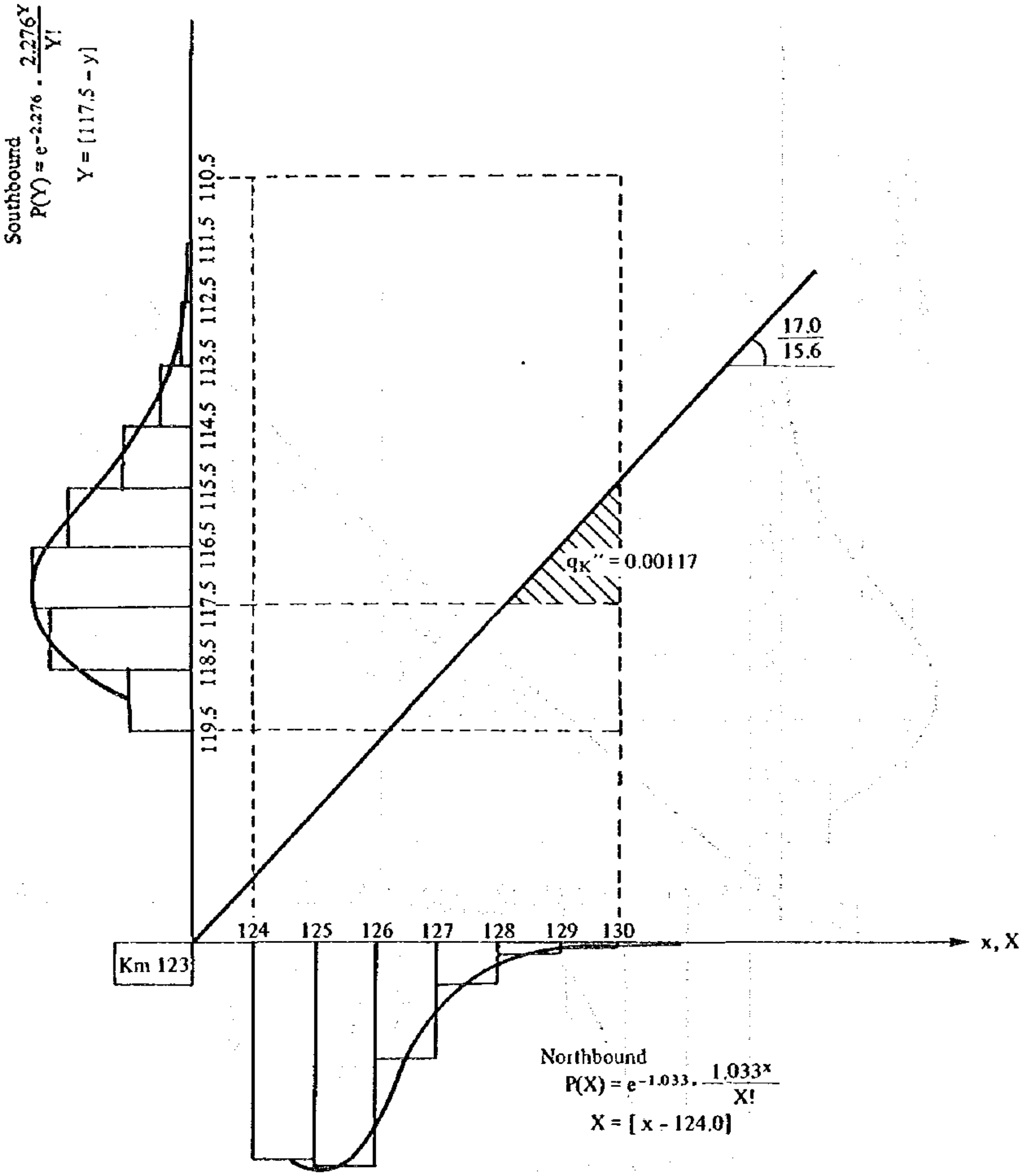


Fig. V-2-(1)-27(3) Encounter Model at Km 123

In Tables V-2-(1)-25 and V-2-(1)-26 the results of sensitivity analysis on the above two cases are shown.

We can note the following tendencies from these results.

Reducing vessel velocity of the posterior convoy (Vy) to 80% (0.8V) the probability of collision at the junction is reduced by about 10^{-1}.

Shifting the arrival point of the posterior convoy at the junction 2 km backward, which is equal to delaying the arrival by about 7 – 8 minutes, the probability of collision at the junction is reduced by about 10^{-2}.

Table V-2-(1)-25 Probability of Collision Occurrence at Junctions
(Case: ALT. 1)

Stage \ Location	Km 61	Km 94	Km 123
The First Stage Development Project	5.167×10^{-8} 5.039×10^{-8}	1.060×10^{-7} 1.153×10^{-7}	3.311×10^{-9} 3.325×10^{-9}
Under Construction (1990)	3.613×10^{-8} 3.524×10^{-8}	7.415×10^{-8} 8.066×10^{-8}	2.315×10^{-9} 2.325×10^{-9}
The Second Stage Development Project (2000)	3.356×10^{-8} 3.272×10^{-8}	6.886×10^{-8} 7.490×10^{-8}	2.150×10^{-9} 2.159×10^{-9}

Note: Upper row: Up to 110,000 DWT
Low row: Over 110,000 DWT

Table V-2-(1)-26 Probability of Collision Occurrence at Junctions
(Case: ALT. 2)

Stage \ Location	Km 61	Km 94	Km 123
The First Stage Development Project	2.006×10^{-8} 1.850×10^{-8}	3.510×10^{-8} 3.083×10^{-8}	1.553×10^{-9} 1.348×10^{-9}
Under Construction (1990)	1.403×10^{-8} 1.294×10^{-8}	2.454×10^{-8} 2.155×10^{-9}	1.086×10^{-9} 9.424×10^{-10}
The Second Stage Development Project (2000)	1.303×10^{-8} 1.201×10^{-8}	2.279×10^{-9} 2.001×10^{-9}	1.008×10^{-9} 8.753×10^{-10}

Note: Upper row: Up to 110,000 DWT
Low row: Over 110,000 DWT

4) Probability of Rear-end Collision

(i) General Structure of the Model

The basic structure of the rear-end collision model is shown in Fig. V-2-(1)-28 and the situation in which collisions happen is shown in Fig. V-2-(1)-29.

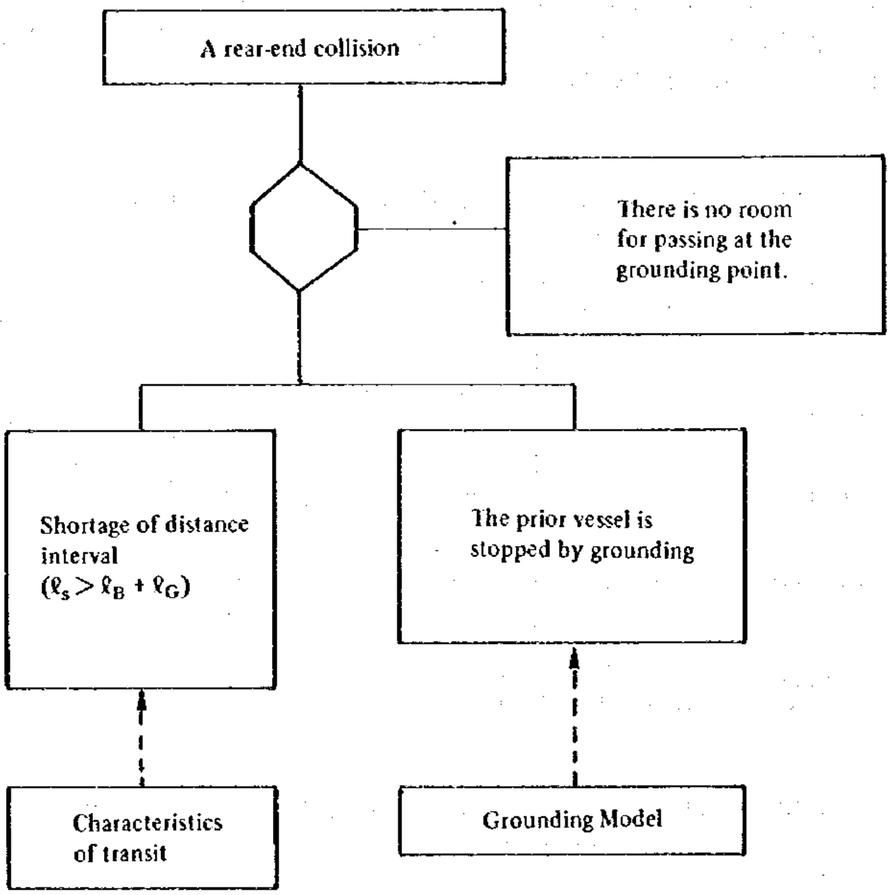
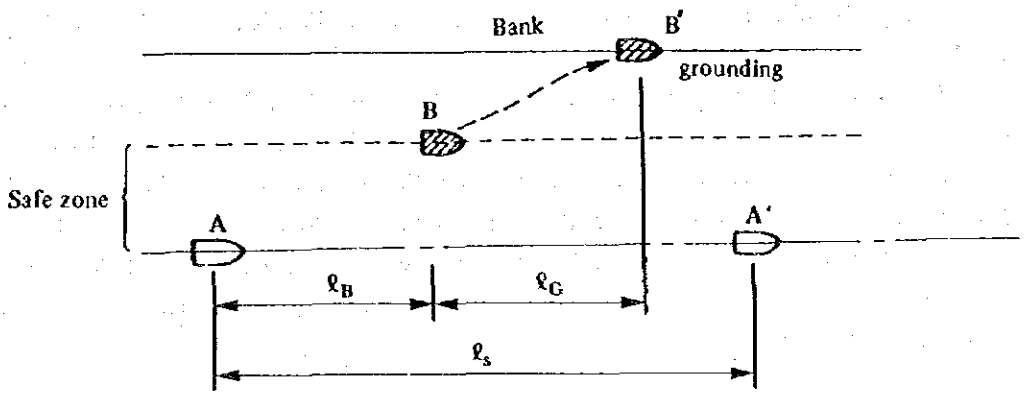


Fig. V-2-(1)-28 Fault Tree for Rear-end Collisions



where ℓ_s : Stopping distance
ℓ_B : Distance between vessels
ℓ_G : Distance between occurrence of human or mechanical error and grounding
note: If $L_s < L_B + L_G$, an accident will not occur.

Fig. V-2-(1)-29 Rear-end Collision Model

Supposing that the distribution of distance between vessels is a normal distribution, the probability of insufficient distance between vessels (P_B) is the shaded part ▨ of Fig. V-2-(1)-30.

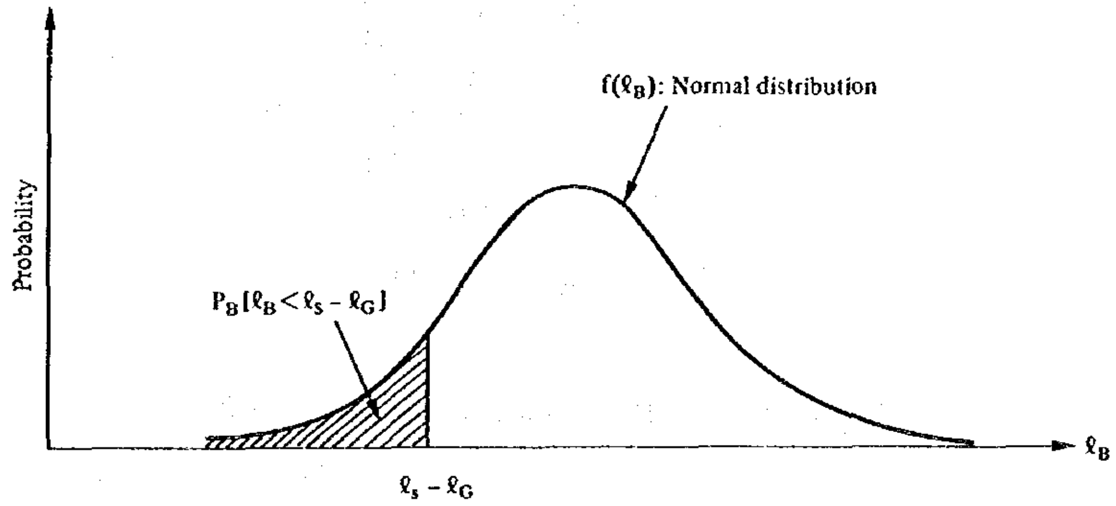


Fig. V-2-(1)-30 Distribution of Distance Interval between Vessels

The probability of grounding of a preceding vessel (P_G) is obtained using the grounding model.

If a vessel with length L grounds and takes a position θ to the channel's orthogonal direction, then the room for passing is represented as $W\text{-}L\cos\theta$ (W: canal width).

So the probability of no room for passing (P_R) is defined as P_R $[W\text{-}L\cos\theta \leqq B]$, where B is the maximum breadth of the following vessel as is shown in Fig. V-2-(1)-31.

P_R $[W\text{-}L\cos\theta \leqq B]$ is equal to P_R $[\theta \leqq \theta c]$, where θc is $\theta c = \cos^{-1} [(W - B)/L]$

Then, assuming that vessels take positions randomly when grounding, P_R $[\theta < \theta c]$ is equal to $2\,\theta c/180°$.

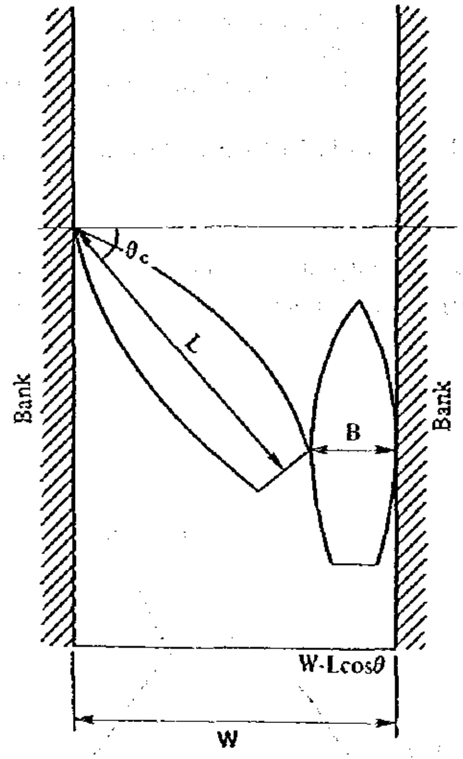


Fig. V-2-(1)-31 Critical Situation for Rear-end Collision

Therefore, we can calculate the probability of rear-end collisions (P) by the following equation:

$P = P_B \times P_G \times P_R$

Where, P_B : Probability of insufficient distance between vessels
P_G : Probability of preceding vessel having a grounding accident
P_R : Probability of no room for passing beside the grounded vessel

(ii) Calculation Results of Probabilities of Rear-end Collision

Firstly, the values of the critical distance between vessels for avoiding rear-end collisions are easily obtained as shown in Table V-2-(1)-27.

Table V-2-(1)-27 The Value of the Term L_S-L_G

Size Categories	Representative Size	V (m/s)	T*	Advanced Distance V · T L_G	Stopping Distance L_S	Critical Distance between Vessels $L_S - L_G$
0 ~ 10,000 DWT	5,000 DWT	4.6 m/s (16.5 km/h) From Diagram	(sec) 31.5	(m) 145	(m) 1,016	(m) 871
10,000 DWT ~ 50,000 DWT	10,000 DWT		60.9	280	1,672	1,392
	50,000 DWT		188.1	865	3,131	2,266
50,000 DWT ~ 200,000 DWT	150,000 DWT		353.9	1,628	2,285	657

Note: *: $T = [15 \log(DWT) - 47] \sqrt[3]{DWT/V}$

Then, we consider the following assumptions

- The average distance interval ($\overline{\ell_B}$) by vessel size is similar to the distances represented by the time figures presented in Table V-2-(1)-28 (time figures can be converted to distance using speed).
- The coefficient of variation on distance interval (CV) is equal to the one Northbound at Deversoir obtained from the diagram in August 1983 (CV = 0.23).

Therefore, the probability of insufficient distance between vessels can be calculated as shown in Table V-2-(1)-29.

Table V-2-(1)-28 Actual Time Interval Data

(minutes)

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

Note: The record of time interval was obtained by processing the actual transit record from Sep. 1 to 15, 1979.

Table V-2-(1)-29 Probability of Insufficient Distance between Vessels

Typical Vessel Size	$L_s - L_G$	$\bar{\ell}B$	$(s = \overline{\ell B} \times CV)$	$u^* = \frac{(L_s - L_G) - \ell B}{s}$	$P(\ell B < u^*)$
5,000 DWT	871 m	2,368 m	545 m	-2.747	3.10×10^{-3}
10,000 DWT	1,392	2,500	575	-1,927	2.44×10^{-2}
50,000 DWT	2,266	4,480	1,030	-2,150	1.58×10^{-2}
150,000 DWT	657	5,500	1,265	-3,828	5.0×10^{-5}

Note: The value of $\bar{\ell}B$ is converted using the velocity of the vessels (V = 16.5 km/hr)

Finally, using the estimate of the probability of grounding accident occurrences, the probability of rear-end collisions are estimated by stages as shown in Tables V-2-(1)-30 and V-2-(1)-31.

The calculation result for total probability at present is 0.87×10^{-6}, whereas only one accident of this type happened in '81 and '82, meaning that one is $1/44,122 = 2.27 \times 10^{-5}$. This difference is based on unidentified risk factors which will not change after the Second Development Project. So the probabilities after the Second Stage Development Project Table V-2-(1)-32 are obtained by multiplying 26.0 (the above-mentioned difference between observed and calculated risk) by the models' output.

Table V-2-(1)-30 Probability of Rear-end Collision of Transit Vessels at Present

		5,000 DWT	10,000 DWT	50,000 DWT	150,000 DWT	Total
	Km Km					
1	19 ~ 31	0.	0.	2.16×10^{-5}	8.84×10^{-8}	1.38×10^{-6}
2	31 ~ 34			0.0	0.0	0.0
3	34 ~ 50			2.86×10^{-5}	1.17×10^{-7}	1.87×10^{-6}
4	64 ~ 71			2.34×10^{-5}	9.1×10^{-8}	1.48×10^{-6}
5	83 ~ 55			0.0	0.0	0.0 x
6	88 ~ 93			5.72×10^{-6}	2.29×10^{-8}	3.64×10^{-7}
7	132 ~ 134			4.68×10^{-6}	2.11×10^{-8}	2.86×10^{-7}
8	134 ~ 145			1.17×10^{-5}	4.42×10^{-8}	7.28×10^{-7}
9	145 ~ 147			0.0	0.0	0.0
10	147 ~ 154			1.17×10^{-5}	4.42×10^{-8}	7.28×10^{-7}
11	1E ~ 15E			5.46×10^{-5}	2.29×10^{-7}	3.38×10^{-6}
12	15E ~ 19E			0.0	0.0	0.0
13	50W ~ 52W			5.46×10^{-6}	2.29×10^{-8}	3.38×10^{-7}
14	52W ~ 55W			0.0	0.0	0.0
15	55W ~ 59W			1.66×10^{-5}	6.76×10^{-8}	1.07×10^{-6}
16	59W ~ 64			2.6×10^{-5}	1.14×10^{-7}	1.77×10^{-6}
17	51E ~ 60E			4.16×10^{-6}	1.64×10^{-8}	2.6×10^{-7}
18	71 ~ 75			4.68×10^{-6}	2.11×10^{-8}	2.86×10^{-7}
19	75 ~ 83			1.46×10^{-5}	6.24×10^{-8}	9.1×10^{-7}
20	85 ~ 88			9.62×10^{-6}	4.16×10^{-8}	5.98×10^{-7}
21	93 ~ 94			0.0	0.0	0.0
22	94 ~ 96			0.0	0.0	0.0
23	96 ~ 101			2.42×10^{-5}	1.04×10^{-7}	1.53×10^{-6}
24	115 ~ 122			3.9×10^{-5}	1.69×10^{-7}	2.47×10^{-6}
25	122 ~ 126			1.46×10^{-5}	6.24×10^{-8}	9.1×10^{-7}
26	126 ~ 129			1.95×10^{-5}	8.32×10^{-8}	1.22×10^{-6}
27	129 ~ 132			4.68×10^{-6}	2.26×10^{-8}	2.86×10^{-7}
28	154 ~ 162			4.68×10^{-6}	2.11×10^{-8}	2.86×10^{-7}
29	Hm0 ~ Hm90			0.0	0.0	0.0
Total				3.38×10^{-4}	1.48×10^{-6}	2.26×10^{-5}

Table V-2-(1)-31 Probability of Rear-end Collision of Transit Vessels after the Second Stage Development Project

		5,000 DWT	10,000 DWT	50,000 DWT	150,000 DWT	Total	Probability/km
	Km Km						
1	19 ~ 31	0.	0.	0.20×10^{-5}	0.21×10^{-7}	0.13×10^{-6}	0.11×10^{-7}
2	31 ~ 34			0.0	0.0	0.0	0.0
3	34 ~ 50			0.15×10^{-5}	0.21×10^{-7}	0.10×10^{-6}	0.60×10^{-8}
4	64 ~ 71			0.18×10^{-5}	0.17×10^{-7}	0.11×10^{-6}	0.17×10^{-7}
5	83 ~ 55			0.0	0.0	0.0	0.0
6	88 ~ 93			0.10×10^{-5}	0.70×10^{-8}	0.62×10^{-7}	0.13×10^{-7}
7	132 ~ 134			0.26×10^{-5}	0.14×10^{-7}	0.17×10^{-6}	0.86×10^{-8}
8	134 ~ 145			0.20×10^{-5}	0.16×10^{-7}	0.13×10^{-6}	0.12×10^{-7}
9	145 ~ 147			0.0	0.0	0.0	0.0
10	147 ~ 154			0.20×10^{-5}	0.15×10^{-7}	0.13×10^{-6}	0.18×10^{-7}
11	1E ~ 15E			0.20×10^{-5}	0.29×10^{-7}	0.13×10^{-6}	0.91×10^{-8}
12	15E ~ 19E			0.0	0.0	0.0	0.0
13	50W ~ 52W			0.42×10^{-6}	0.52×10^{-8}	0.26×10^{-7}	0.14×10^{-7}
14	52W ~ 55W			0.0	0.0	0.0	0.0
15	55W ~ 59W			0.15×10^{-5}	0.26×10^{-7}	0.10×10^{-6}	0.24×10^{-7}
16	59W ~ 64			0.21×10^{-5}	0.29×10^{-7}	0.14×10^{-6}	0.26×10^{-7}
17	51E ~ 60E			0.21×10^{-6}	0.29×10^{-8}	0.14×10^{-7}	0.15×10^{-8}
18	71 ~ 75			0.78×10^{-6}	0.60×10^{-8}	0.49×10^{-7}	0.12×10^{-7}
19	75 ~ 83			0.25×10^{-5}	0.26×10^{-7}	0.16×10^{-6}	0.21×10^{-7}
20	85 ~ 88			0.19×10^{-5}	0.26×10^{-7}	0.12×10^{-6}	0.39×10^{-7}
21	93 ~ 94			0.0	0.0	0.0	0.0
22	94 ~ 96			0.0	0.0	0.0	0.0
23	96 ~ 101			0.18×10^{-5}	0.19×10^{-7}	0.11×10^{-6}	0.23×10^{-7}
24	115 ~ 122			0.25×10^{-4}	0.14×10^{-6}	0.16×10^{-5}	0.23×10^{-6}
25	122 ~ 126			0.10×10^{-4}	0.55×10^{-7}	0.65×10^{-6}	0.17×10^{-6}
26	126 ~ 129			0.31×10^{-5}	0.42×10^{-7}	0.22×10^{-6}	0.70×10^{-7}
27	129 ~ 132			0.12×10^{-5}	0.15×10^{-7}	0.78×10^{-7}	0.26×10^{-7}
28	154 ~ 162			0.15×10^{-5}	0.15×10^{-7}	0.10×10^{-6}	0.12×10^{-6}
29	Hm0 ~ Hm90			0.0	0.0	0.0	0.0
Total				0.68×10^{-4}	0.55×10^{-6}	0.42×10^{-5}	

5) Probability of Collision at Two-way Passes

(i) General Structure

Fig. V-2-(1)-32 shows the basic structure of the collision model at two-way passes without separation facilities.

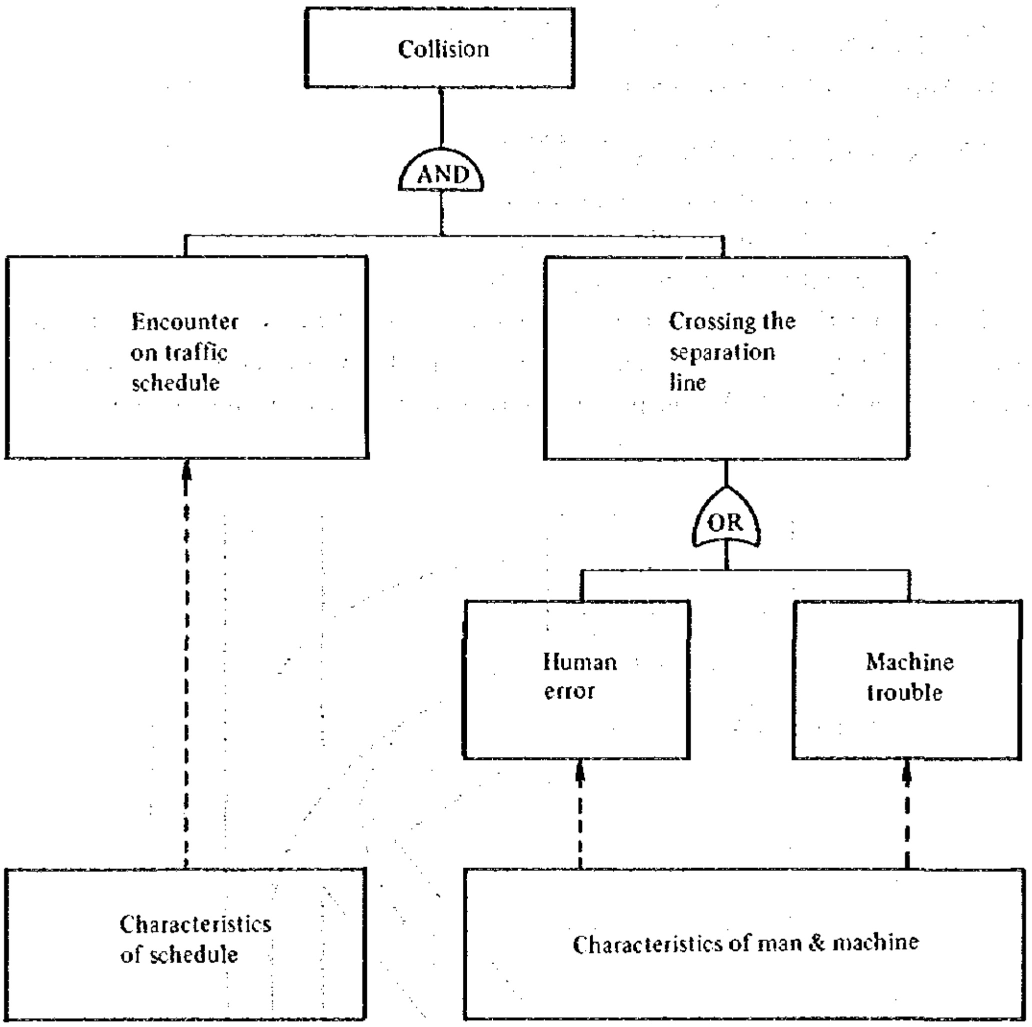


Fig. V-2-(1)-32 Basic Structure of Collision Model at the Two-way Passes

(ii) Calculation Results of Probabilities for Collision at Two-way Passes

The probability of encounter at each objective two-way pass Pk is estimated by using the data from the traffic diagram of August 1983 and the SCVTMS as follows:

- South Light (Km 114)

$$Pk = \frac{Ne}{Nn + Ns} = \frac{223}{875 + 954} = 2.44 \times 10^{-1}$$

- North Light (Km 106)

$$Pk = \frac{Ne}{Nn + Ns} = \frac{362}{875 + 954} = 1.98 \times 10^{-1}$$

- East Approach Channel (Hm 80)

$$Pk = \frac{Ne}{Nn + Ns} = \frac{6}{875 + 954 \times 0.7} = 3.89 \times 10^{-3}$$

where: Nn : Number of Northbound vessels
Ns : Number of Southbound vessels
Ne : Number of encountering vessels

Ns at point Hm 80 Port Said is assumed to be 70% of the total number of southbound vessels considering that only vessels entering the port have the possibility of encountering as shown in Fig. V-2-(1)-33. This proportion is assumed based on data for tankers.

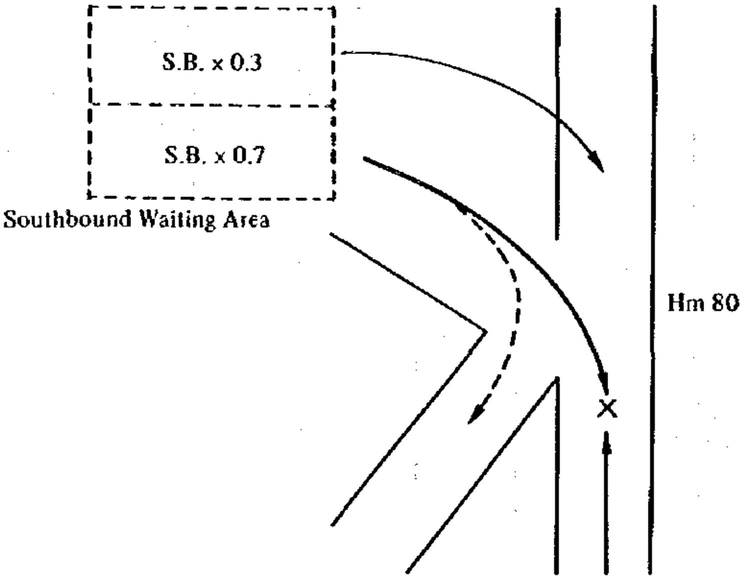


Fig. V-2-(1)-33 The Number of Southbound Vessels Entering the Bypass

The probability of machine trouble Pk is calculated using the stopping distance So and the probability of Pk per Km is shown in Table V-2-(1)-32.

Table V-2-(1)-32 Probability of Machine Trouble Pk

Vessel Size	Stopping Distance	Pk per Km	Probability
Up to 110,000 DWT	3.13 Km	Failure/km 2.98×10^{-5}	9.33×10^{-5}
Over 110,000 DWT	2.29		6.82×10^{-5}

Note: Stopping distance is calculated assuming velocity of vessels is 16.5 km/hr.

And, the probability of human error occurrence (Ph) is assumed as the usually used value of 10^{-3}.

Therefore, based on Fault Tree Analysis as mentioned above (Fig. V-2-(3)-19), the probability of collisions at two-way passes without separation facilities at three locations is shown in Table V-2-(1)-33.

Table V-2-(1)-33 Probability of Collisions at Two-way Passes without Separating Facilities

Vessel Size Location	Up to 110,000 DWT	Over 110,000 DWT
South Light	2.67×10^{-4}	2.61×10^{-4}
North Light ~ South Light	2.16×10^{-4}	2.12×10^{-4}
Hm 80 in Port Said	4.25×10^{-6}	4.16×10^{-6}

6) Probability of Collision at Waiting Areas

(i) General Structure

When ship A intends to anchor at point P, the operator observes the distance to point P and starts stopping when he observes. That he is at the distance s (k) from point P.

Let's denote the observed value of distance by ym and its real distance by y. When he considers that he has to stop at least in the domain D in order to avoid a collision, he might start stopping when he observes his distance to P as S (k) taking into consideration that he still has a distance r as a safety margin. Under such conditions, dangerous situations will occur if he believes the distance to the point Q is more than S (k) + 2r when he starts stopping while the real distance is less than or equal to S (k). Therefore the probability that dangerous situations occur is given by:

$$Pr = \text{Prob.}\ [ym \geq S(k) + 2r \mid y = S(k), C]$$

$$= \int_{s(k)+2r}^{\infty} \phi m\,(ym \mid y = s(k))\, dym \times \text{Prob.}\ [C]$$

$$= \int_{s(k)+2r}^{\infty} \frac{1}{\sqrt{2r\sigma}} \exp\left[-\frac{1}{2}\left(\frac{ym - f(s(k))}{\sigma}\right)^2\right] dy_m \times \text{Prob.}\ [C]$$

$$= \left[1 - \Phi\left(\frac{S(k) + 2r - f(s(k))}{\sigma}\right)\right] \times \text{Prob.}\ [C]$$

Where f (s (k)) is the mean and σ is the standard deviation of ym corresponding to y = s (k), k is the parameter of size of ship A, and C is the condition that another ship has been anchored on the course.

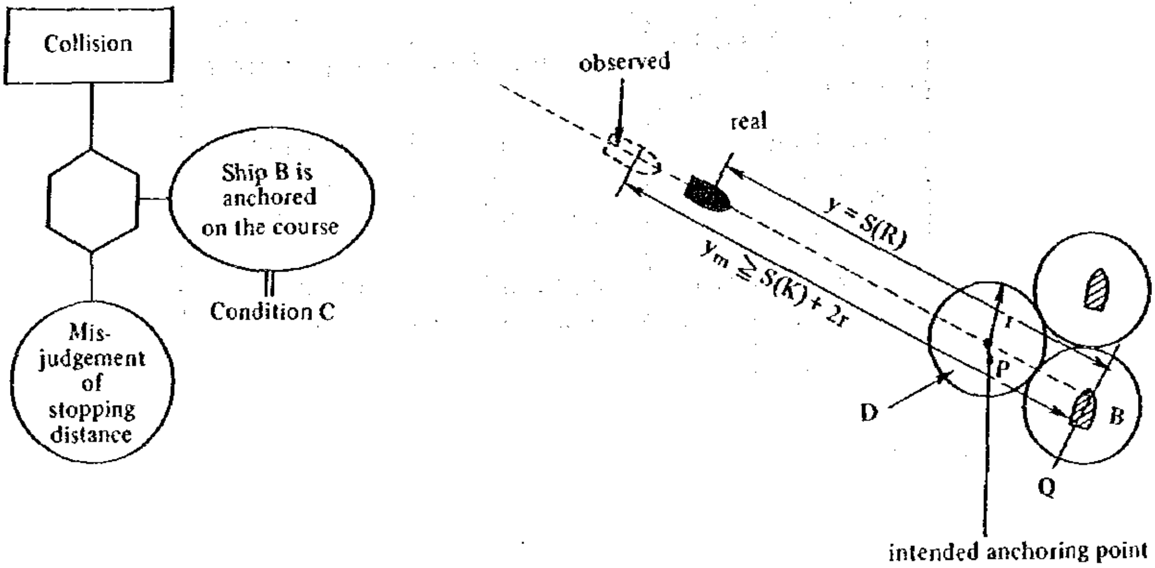


Fig. V-2-(1)-34 Fault Tree and Collision Model at Waiting Area

When a ship gets in such a dangerous situation, the probability that she fails to avoid the collision is given by

$$Pf = \frac{PG}{Pr}$$

PG: Observed probability of collisions at waiting areas

(ii) Calculation Results of Probability at Waiting Areas

i) Premises

All the risk factors which are considered in the model are as follows:

- Vessel size (k)
- Stopping distance (S (k): See Table V-2-(1)-22)
- Eye measurement distance when the real distance is S (k) (f (S (k)): See Fig. V-2-(1)-19)
- Standard deviation of eye measurement distance (σ: See V-2-(1)-(iii)-V)
- Safety margin (r)
- Condition that another ship is anchored on the course (C)

Table V-2-(1)-34 Data for Collision Probability at Waiting Areas (1)

K (DWT)	S (k) (km)	f (S (k)) (km)	σ (km)	P [C]
0 ~ 50,000	3.0	3.06	1.87	0.3
50,000 ~	2.2	2.74	1.67	

Note: P [C] is evaluated by observation data from 1984.

Table V-2-(1)-35 Data for Collision Probability at Waiting Areas (2)

Location	γ (km)
Port Said	0.564
Great Bitter Lake	0.535

Note: r is evaluated by observation data from 1984.

ii) Results

The probability that a dangerous situation occurs (Pr), the probability that a ship fails to avoid the collision (Pf), and the collision probability at waiting areas (P_G) are shown in Table V-2-(1)-36.

Table V-2-(1)-36 Collision Probability at Present

Item / Location / Ship Size	Pr		Pf		P_G	
	Port Said	Great Bitter Lake	Port Said	Great Bitter Lake	Port Said	Great Bitter Lake
0 ~ 50,000	0.084	0.087	5.39×10^{-4}	1.04×10^{-3}	4.53×10^{-5}	9.07×10^{-5}
50,000 ~	0.108	0.111	4.19×10^{-4}	8.17×10^{-4}		

Note: P_G is evaluated using the observed probability in '81 ~ '82.

(iii) Sensitivity Analysis

When the safety margin increases 20% (0.564 → 0.677, 0.535 → 0.642), the collision probability (P_G) is shown in Table V-2-(1)-37.

Table V-2-(1)-37 Collision Probability at Waiting Areas

Item / Location / Ship Size	Pr		Pf		P_G	
	Port Said	Great Bitter Lake	Port Said	Great Bitter Lake	Port Said	Great Bitter Lake
0 ~ 50,000	0.075	0.078	5.39×10^{-4}	1.04×10^{-3}	4.04×10^{-5}	8.11×10^{-5}
50,000 ~ 100,000	0.093	0.099	4.19×10^{-4}	8.17×10^{-4}	3.90×10^{-5}	8.09×10^{-5}

(2) Estimation of Cargo Hazards

1) Nature of Crude Oil, LPG and LNG

(i) Properties of Crude Oil, LPG and LNG

Crude oil is the mixture of many types of hydrocarbons as pumped up from the oil field. Chemical composition and properties of crude oil depend on the place of origin as shown in Table V-2-(2)-1.

Table V-2-(2)-1 Properties of Crude Oil

	Name of Crude Oil	Arabian Light	Arabian Heavy	Iranian Light	Iranian Heavy	Kuwait
General properties of crude oil (Example)	Specific Gravity (15/4°C)	0.852	0.887	0.855	0.871	0.868
	API Degree	33.5	27.7	33.9	31.5	30.9
	Vapor Pressure (kg/cm², 37.8°C)	0.35	–	0.52	–	–
	Kinetic Viscosity (cSt, 30°C)	6.90	22.4	4.7 (50°C)	6.5 (50°C)	7.0 (50°C)
	Pour Point (°C)	–15 >	–20 >	–15 >	–12.5	–10
	Wax (W%)	–	2.2	6	–	2.6
	Sulfur (W%)	1.72	2.70	1.40	1.71	2.6
	Nitrogen (W%)	0.09	–	–	0.22	0.16
	Residual Carbon (W%)	3.1	7.2	3.4	5.20	5.3
	Water Sludge (V%)	0.05	0.3	–	0.15	0.1
	Moisture (V%)	0.05	0.2	–	0.1 >	0.1 >
	Salt (W%)	3	0.0110	–	0.0039	0.0009
	Heavy Metals { V (ppm)	12	–	–	63	–
	Heavy Metals { Ni (ppm)	4	–	–	16	–
Properties of each fraction (Example)	Gasoline Fraction					
	Distillation Range (°C)	20 ~ 160	60 ~ 160	C_5^+ ~ 165	IBP ~ 85 85 ~ 160	IBP ~ 190
	Yield (V%)	25.0	20.0	21.1	6.5 12.6	19.5
	Specific Gravity (15/4°C)	0.7091	0.722	–	0.665 0.745	0.718
	Octane Value Clear	41	–	68 (light naphtha)	69 –	61.2
	Octane Value 1.1 cc/gal	–	–	–	– –	–
	Kerosine Fraction					
	Distillation Range (°C)	160 ~ 221	160 ~ 230	160 ~ 235	160 ~ 240	190 ~ 250
	Yield (V%)	13.5	10.0	13.2	14.1	11.6
	Specific Gravity (15/4°C)	0.7973	0.789	0.797	0.795	0.790
	Gas Oil Fraction					
	Distillation Range (°C)	221 ~ 316	230 ~ 300	235 ~ 300 300 ~ 350	240 ~ 320 320 ~ 330	250 ~ 300
	Yield (V%)	13.5	11.0	11.0 8.7	14.0 2.3	12.8
	Specific Gravity (15/4°C)	0.8364	0.841	0.838 0.862	0.845 0.875	0.835
	Sulfur (W%)	0.81	1.69	0.66 1.14	0.91 1.35	0.93
	Nitrogen (W%)	0.001	–	–	0.03 0.07	0.0004
	Residual Carbon (W%)	Trace	–	–	– –	–
	Atmospheric Residual Oil					
	Distillation Range (°C)	316 ~	300 ~	350 ~	330 ~	300 ~
	Yield (%)	48.0	56.5	43.5	49.0	53.2
	Specific Gravity (15/4°C)	0.9433	1.004	0.951	0.955	0.958
	Kinetic Viscosity (cSt, 50°C)	90	249	190	150	220
	Pour Point (°C)	+5	+7.5	+24	+15	+12.5
	Sulfur (W%)	2.86	4.51	2.53	2.6	4.0
	Nitrogen (W%)	0.18	–	–	0.41	0.20
	Residual Carbon (W%)	7.2	11.8	6.0	8.9	9.4
	Heavy Metals { V (ppm)	38	–	–	119	51
	Heavy Metals { Ni (ppm)	8	–	–	31	14

LPG is the acronym for Liquefied Petroleum Gas with the major component of propane, and the properties of LPG resemble to propane. LNG is the acronym for Liquefied Natural Gas with the major component of methane, and the properties of LNG resemble to methane. See Table V-2-(2)-2.

Table V-2-(2)-2 Properties of Methane and Propane

Name Item		Methane	Propane
Molecular Formula		CH_4	C_3H_8
Molecular Weight		16.04	44.09
Gas Density kg/m^3	0°C 1 Ata	0.7168	2.0200
Gas Specific Gravity (Air = 1)	0°C 1 Ata	0.5544	1.562
Liquid Density kg/liter	0°C 1 Ata		0.5282*
	20°C 1 Ata		0.5005*
Vapor Pressure Ata	0°C	(176)	4.7
	20°C	(293)	8.0
Melting Point	°C 1 Ata	-182.48*	-187.69*
Boiling Point	°C 1 Ata	-161.49	-42.07
Critical Temperature	°C	-82.5	96.81
Critical Pressure Ata		45.80	42.01
Critical Density kg/liter		0.162	0.220
Latent Heat of Evaporation (Boiling Point) kcal/kg		121.9	101.8
Gas Specific Heat	Cp**25°C 1 Ata	0.534	0.404
	Cv**25°C 1 Ata	0.401	0.359
Gross Calorific Value (Gas) kcal/kg	25°C 1 Ata	13,265	12,034
Net Heating Value (Gas) kcal/kg	25°C 1 Ata	11,954	11,079
Ignition Temperature	°C	632	481
Explosion Limit in Air Vol%	Lower Limit	5.00	2.37
	Upper Limit	15.00	9.50

* Value at saturated pressure

** Cp: Value at constant pressure, Cv: Value at constant volume

(ii) Effects of Crude Oil, LPG and LNG

The common property of crude oil, LPG and LNG is that they produce flammable vapor at normal temperature.

i) Effect of Vapor on Human Body

(a) Crude Oil Vapor

Table III-2-(2)-3 shows that crude oil vapor first irritates eyes and secondly causes headache. As the symptom proceeds, cheeks glow, and nerve systems are attacked losing control with an enhanced humor. Even lean crude oil vapor, its respiration for a long time causes a dim consciousness which may lead to syncope.

Table V-2-(2)-3 *List of Crude Oil Vapor Content in Percent and Clinical Symptoms of Acute Intoxication

Temperature and Time / Crude Oil Gas %	10 ~ 30°C					Remarks
	1 Hour	2 Hours	3 Hours	5 Hours	Over 5 Hours	
0 ~ 0.1	Feeling of drunkeness, pyrexia feeling in whole body (flushed feeling), feeling heavy in head, headache, hyperemia in face.	Occasionally bad headache, occasional vomit, nausea, sneezing, feeling heavy in head, hyperemia in face.	Headache, photopathy, weak steps, dim feeling in head, pale face.	Feeling of compression at breast, hiccups, weak steps, feeling of languishment, pale face.	Vomiting, hard to walk, unstable waist, conscious.	A content below 0.2% is designated as safety range. A long time respiration of 0.1% oil gas often results in working inability.
0.5 ~ 1.5	Dizziness and pale face, occasionally bad headache, stimulation to eyes, slavering, increased pulses.	Bad headache, staggering, vomiting after fever, pale face, hiccups, decreased pulses.	Dizziness, benumbing, swoon, blepharos pasm, decreased pulses.			A 1.0% content can be sensed by smell. Pupil shrink in the beginning. Scattering light.
2.0 ~ 3.0	Dizziness, talking inability, vomiting, walking inability, swoon, increased pulses, pale face.					Excitation period is surely encountered above 2.0%. Symptoms resemble those of excitation period in other anesthesia.
3.0 and above	Swoon, unconscious, whole body convulsions, pale face, incontinent.					Death in 3-5 minutes if if 0.005% of H_2S is contained.

Blank frames suggest death.

* (Clinical example by Dr. Kuga in The Maritime Lavourer Research Institute)

(b) LPG and LNG

Vapor of LPG and LNG is odorless and less toxic in comparison with crude oil vapor. At approx. 2% concentration of propane, the Lower Flammable Limit of propane, the vapor mixture contains enough oxygen to support human activity with only a slight toxicity. However, when LPN or LNG is discharged in large quantity, the atmospheric oxygen concentration drops by the increase of the discharged vapor. When the discharged vapor is ignited causing a big fire, the atmospheric oxygen is consumed in great amounts, and the oxygen content of the ambient air will drop. The oxygen content of ordinary air is 21% which supports human life.

Lack of oxygen leads to danger as follows:

a) Oxygen concentration in air 21%: Normal air
b) Oxygen concentration in air 18%: Safety limit
c) Oxygen concentration in air 16%: Tachypnea, increased pulse, headache, nausea, qualm
d) Oxygen concentration in air 12%: Dizziness, qualm, light myasthenia
e) Oxygen concentration in air 10%: Pale face, unconsciousness, vomiting
f) Oxygen concentration in air 8%: Coma, death after 8 minutes
g) Oxygen concentration in air 6%: Respiration stop, convulsion, death

Since LPG and LNG are stored at very low temperatures, the liquid and the leaking vapor will cause frostbite whenever they contact human skin.

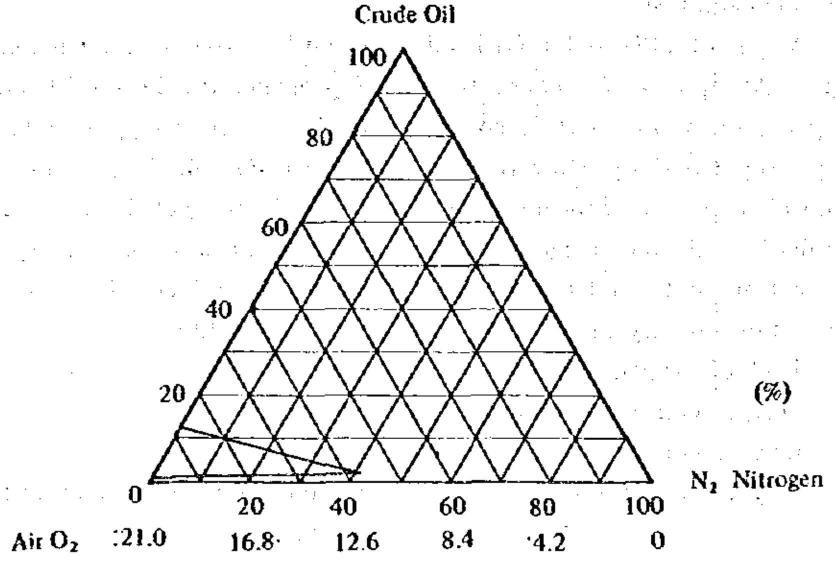
ii) Ignition and Flame (Explosion)

Flame is the oxidizing reaction accompanied by emission of heat and light.

Elements for flame occurrence are the presence of substances to be oxidized; i.e., inflammable materials, the presence of air; i.e., oxygen, and the presence of heat necessary for oxidizing reaction; i.e., ignition energy.

Flame will not occur if any one of these elements is absent. For continuous flame, fuel and oxygen must be continuously supplied. The flame condition is not always constituted at any time. An absolute ratio of vapor mixture (oxygen: fuel) exists with which flame continues under a specific temperature and a specific pressure. The ratio is called the Flammable Limit (Explosive Limit). When the fuel concentration is at the lowest value, the ratio is called the Lower Flammable (Explosive) Limit, and when the fuel concentration is at the highest value, the ratio is called the Upper Flammable (Explosive) Limit.

Figure V-2-(2)-1 shows the general Flammable (Explosive) Range of crude oil vapor, while Figs. V-2-(2)-2 and V-2-(2)-3 show Flammable (Explosive) Ranges of propane and methane.



As for crude oil, the Lower Flammable (Explosive) Limit is represented by hexane, and the Upper Flammable (Explosive) Limit is represented by ethane.

Flammable (Explosive) Range [Enlarged]

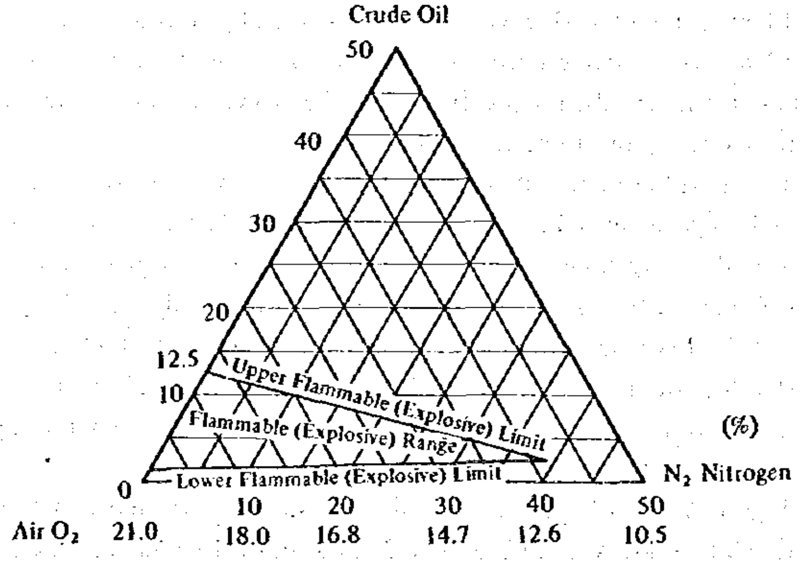
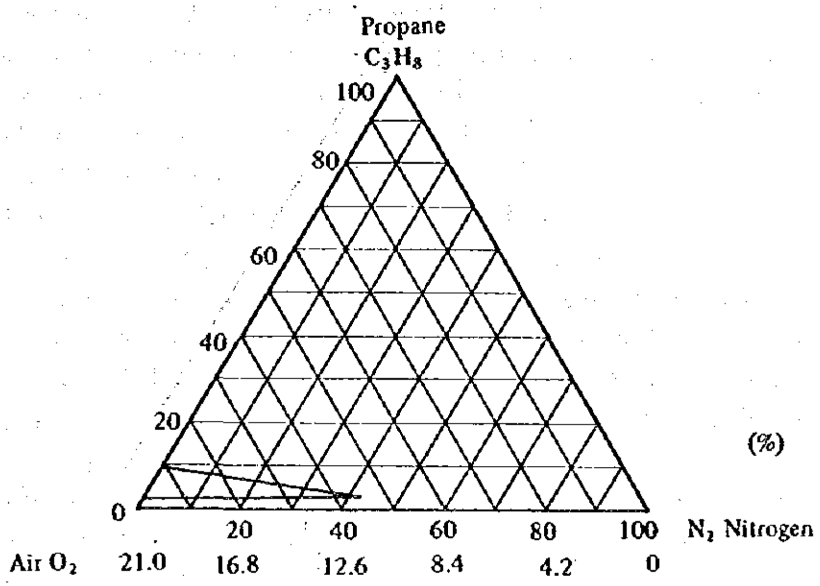


Fig. V-2-(2)-1 Flammable (Explosive) Range of Crude Oil

The above diagram indicates that the Flammable (Explosive) Range of crude oil in air is 1.2 ~ 12.5%, and that flame (Explosion) does not occur at an oxygen concentration of 11% or less.



Flammable (Explosive) Range [Enlarged]

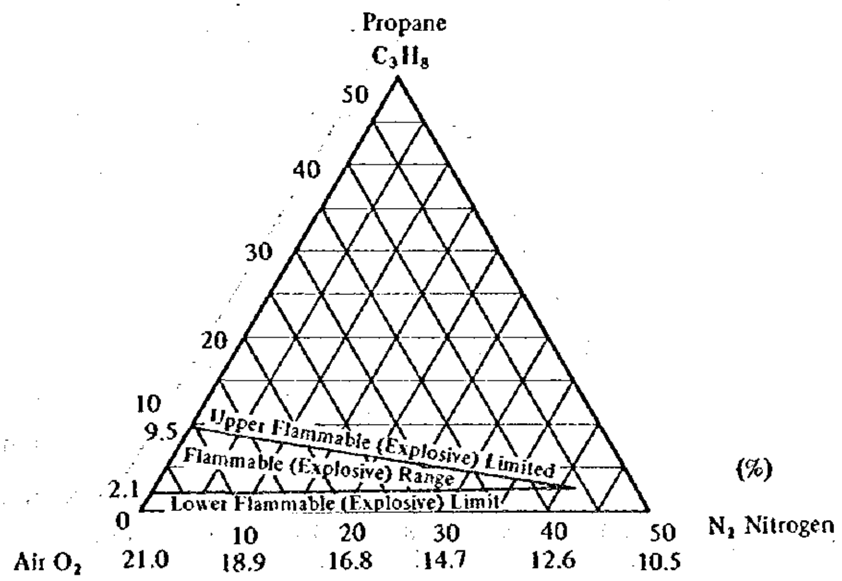
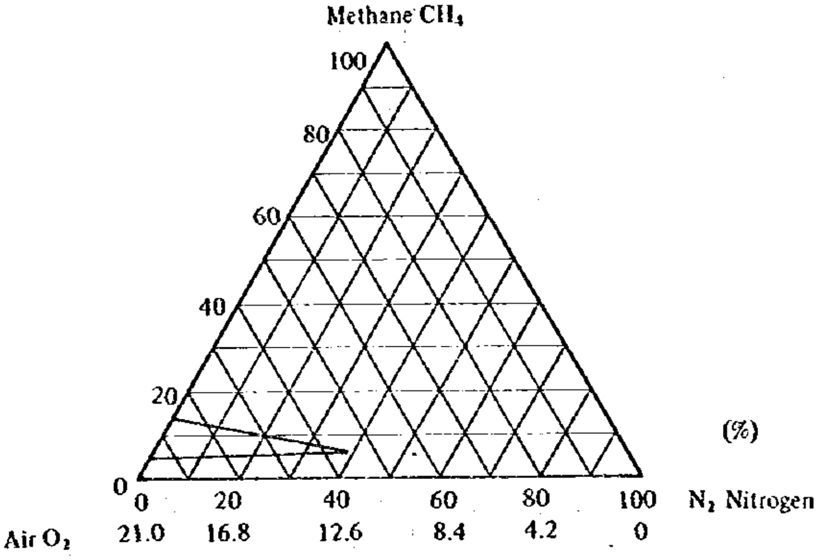


Fig. V-2-(2)-2 Flammable (Explosive) Range of Propane

The above diagram indicates that the Flammable (Explosive) Range of propane in *the air is 2.1 ~ 9.5%, and that flame (explosion) does not occur at an oxygen con*centration of 11% or less.



Flammable (Explosive) Range [Enlarged]

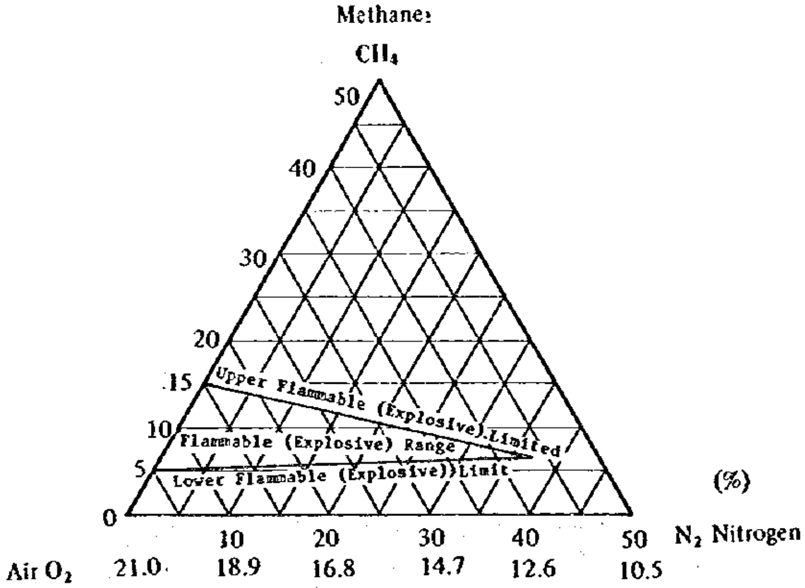


Fig. V-2-(2)-3 Flammable (Explosive) Range of Methane

The above diagram indicates that the Flammable (Explosive) Range of methane in the air is 5 ~ 15%, and that flame (explosion) does not occur at an oxygen concentration of 11% or less.

iii) Spreading of Crude Oil, LPG and LNG on the Sea

When crude oil is discharged on the sea, it spreads on the sea surface continuously according to its specific gravity and viscosity with the vapor of low boiling point components being emanated from the oil.

When LPG or LNG is discharged on the sea, it spreads on the sea surface continuously till it is completely vaporized. So that there will be no *sea-pollution by that. Boiling of the vapor rapidly occurs because of the substantial temperature difference between sea water and the low temperature liquid, and their large contact area will develop a vapor cloud without producing coagulated ice on the water surface.

LPG expands to 260 times in volume when gasified, and stay on the sea surface because the specific gravity of the gas is larger than that of air. LNG expands to 600 times in volume when gasified, but it rises in the atmospheric air because its specific gravity is smaller than that of air at a temperature above −120°C.

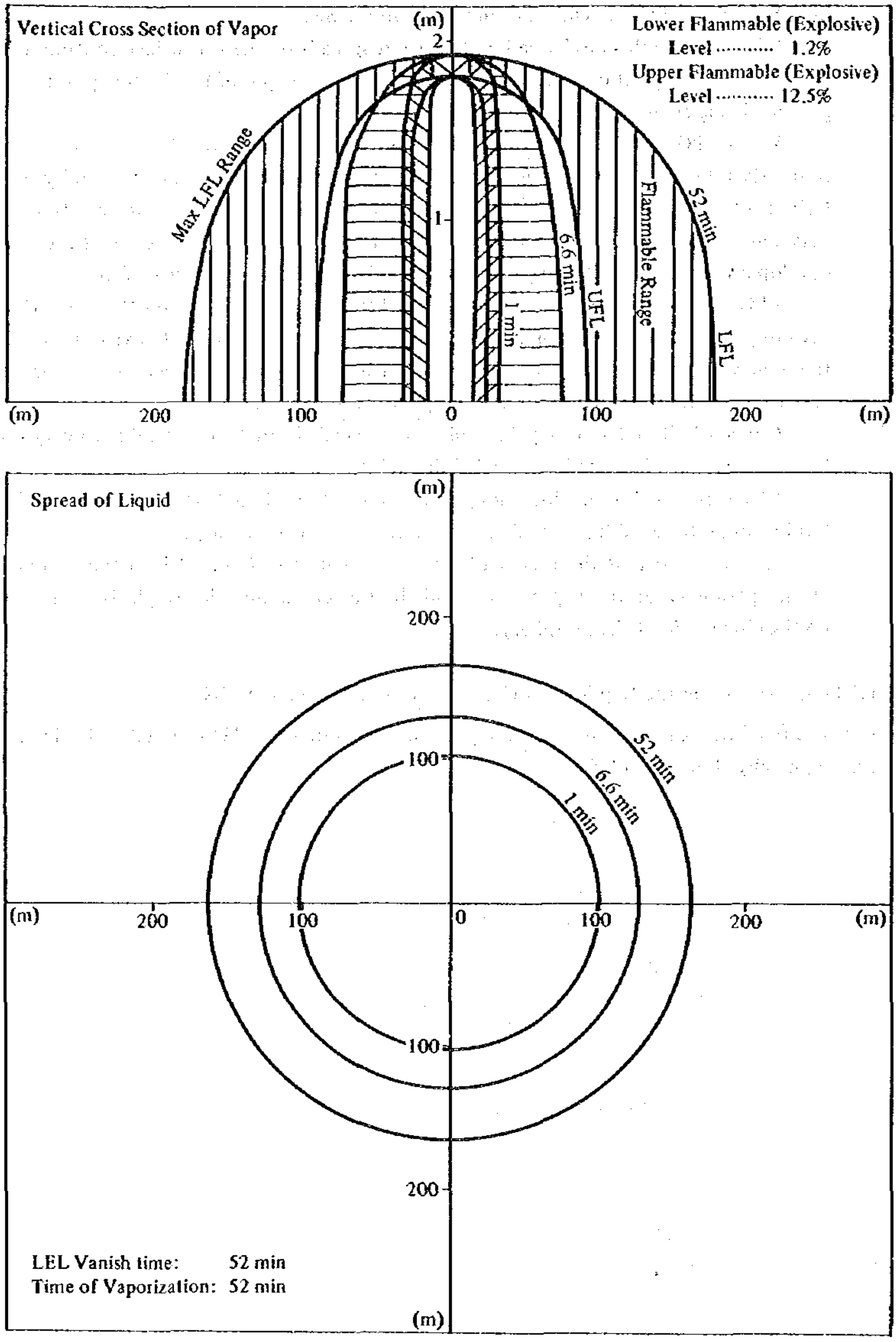
General hull material may be broken by so called brittle fracture due to very low temperature when it is suddenly cooled down by spilling cargo.

Flameless Explosion, does not occur on the fresh liquidified gas and Flameless Explosion on the aged liquidified gas does not cause serious damage.

It is assumed that the Lower Flammable (Explosive) Limit of LPG exists outside of the periphery of the vapor cloud and the Lower Flammable (Explosive) Limit of LNG exists inside of the periphery.

2) Trial Calculations on the Liquids and Gases of Crude oil, LPG and LNG.

The results of trial calculations on the liquids and gases of 1,000 M^3 of Crude oil, LPG and LNG are graphically shown as follows:



Lower Flammable (Explosive) Level 1.2%
Upper Flammable (Explosive) Level 12.5%

LEL Vanish time: 52 min
Time of Vaporization: 52 min

Fig. V-2-(2)-4 Diffusion of Crude Oil (Calm)

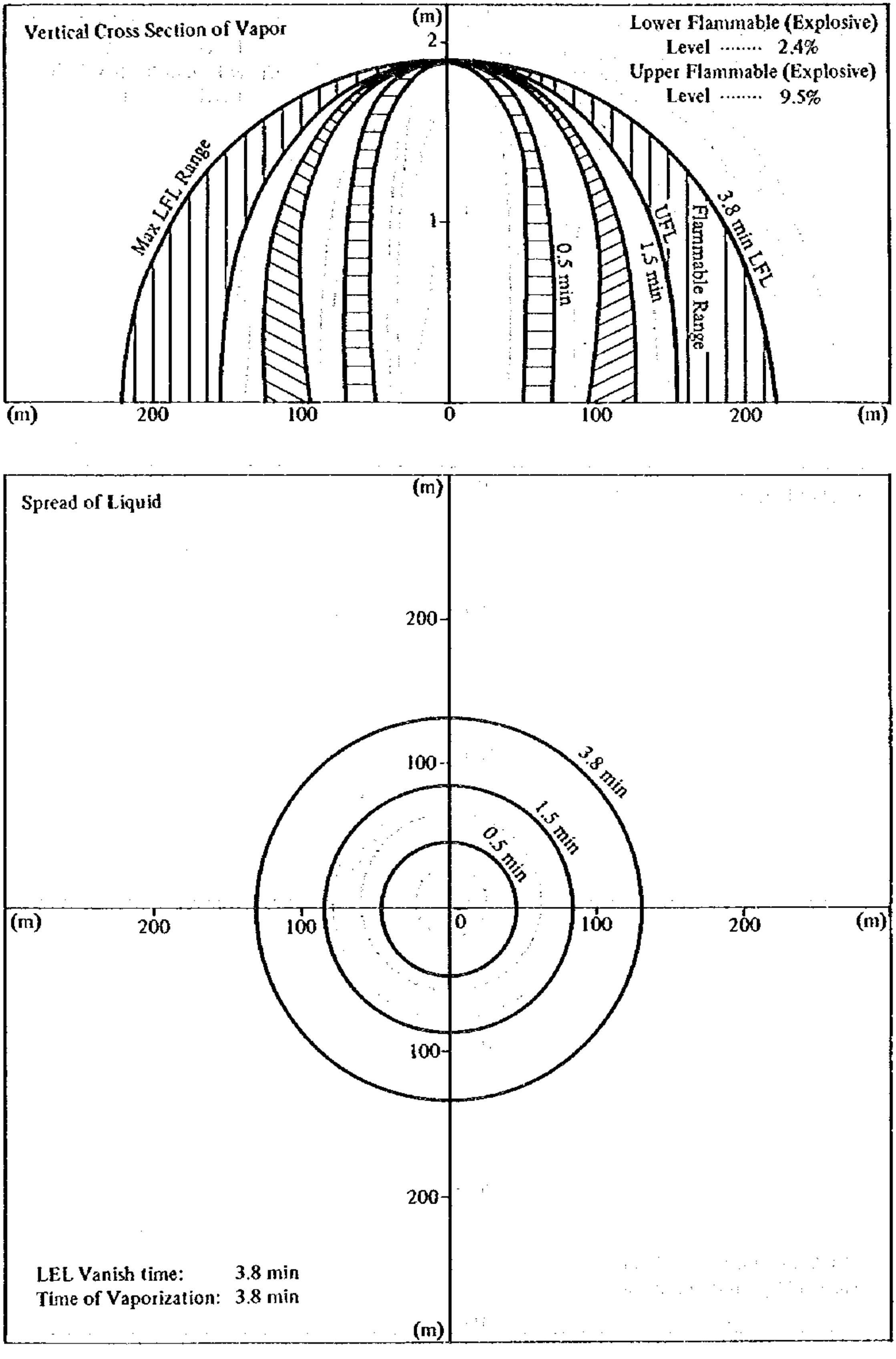


Fig. V-2-(2)-5 Diffusion of LPG (Calm)

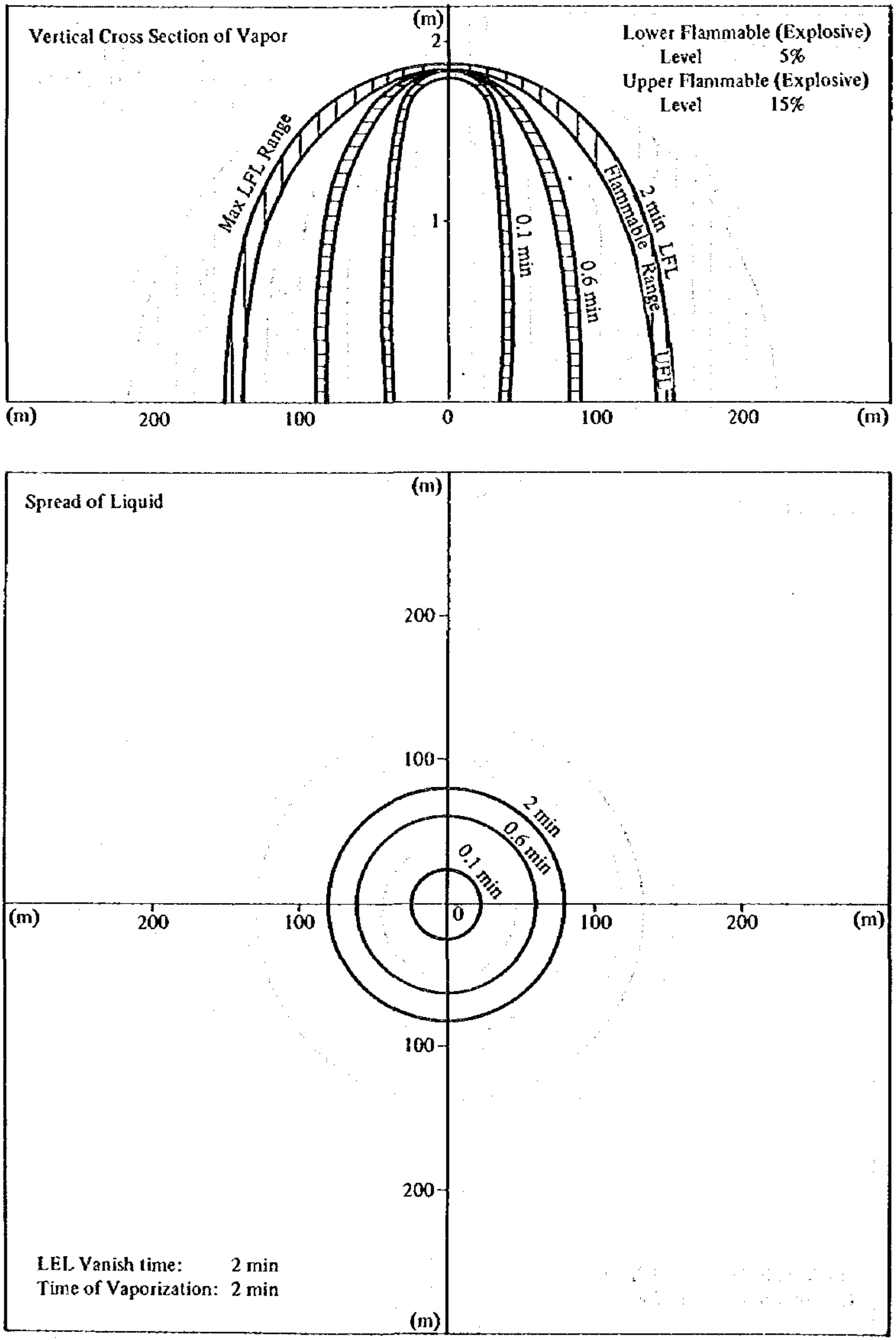


Fig. V-2-(2)-6 Diffusion of LNG (Calm)

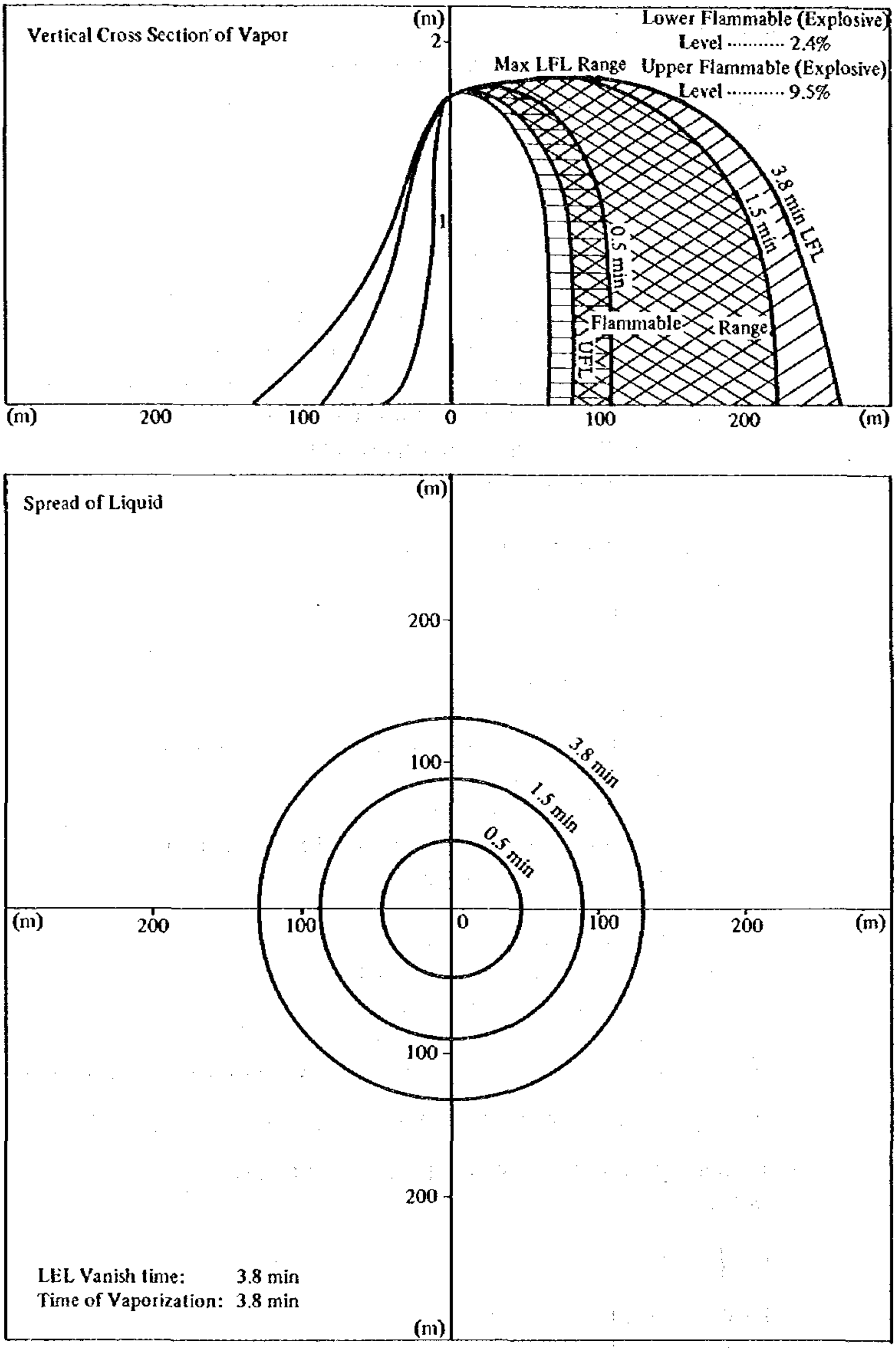


Fig. V-2-(2)-7 Diffusion of LPG (Wind Velocity 3 m/sec)

(i) Used Model

i) Liquid Surface Spreading Model of Crude Oil
(Motora model)

$R = (\alpha \cdot t)^{1/8}$

t : Elapsed time(s)

$$\alpha = \frac{16 \cdot g \cdot V^3}{\pi^3 \cdot c^2 \cdot \upsilon}$$

g : Gravity acceleration (cm/s^2)
V : Volume of oil on the water surface (cm^3)
C : Velocity gradient coefficient of oil (–)
υ : Coefficient of kinematic viscosity of oil (cm^2/s)

Where, the vaporization of crude oil is calculated using the following formula.

$qm = 2.12 \times 10^{-7} \times 22.9 \times (1 + 0.121 \times U^{0.85})$

qm: Rate of vaporization ($gr/s/cm^2$)
U : Gas transfer velocity (cm/s)

ii) Liquid Surface Spreading Model of LPG and LNG
(Shaw – Briscoe model)

$$\begin{cases} V = A + B \cdot t - m/\rho \\ h = V/\pi r^2 \\ r = \sqrt{2 \cdot g \cdot \Delta \cdot h} \\ m = \pi r^2 \cdot \rho \cdot v \end{cases}$$

V : Residual amount of oil at the time "t" (m^3)
A : Momentary spill (m^3/s)
B : Rate of spill (m^3/s)
m : Amount of vaporization until the time "t" (kg)
ρ : Density of liquid (kg/m^3)
h : Height of residual liquid (m)
r : Radius of liquid surface (m)
g : Gravity acceleration (m/s^2)
Δ : Coefficient of buoyancy (–)
v : Rate of vaporization (m/s)

Where the coefficient of buoyancy is obtained by using the following formula:

$\Delta = \frac{\rho w - \rho}{\rho w}$ ρw: Density of sea water

iii) Diffusion Model of Crude Oil Gas, LNG Gas and LPG Gas
(Sakagami model)

$$\bar{C} = \int_k^{\pi} ct \cdot dt$$

$$\begin{cases} k = 0 & \tau \leq T \\ k = \tau - T & \tau > T \end{cases}$$

T: Vaporization completion time

Ct: Gas density from the Sakagami model's instantaneous plane source.

$$Ct = Q(t) \cdot \frac{e^{-\frac{Z+H}{B}}}{B} \cdot \frac{1}{2} \{ \mathrm{erf}(\frac{x - u \cdot t + R}{\sqrt{A}}) - \mathrm{erf}(\frac{x - u \cdot t - R}{\sqrt{A}})] \cdot \frac{1}{2}$$

$$\cdot [\mathrm{erf}(\frac{y + R}{\sqrt{A}}) - \mathrm{erf}(\frac{y - R}{\sqrt{A}})] \; Io(2 \cdot \sqrt{\frac{hz}{B}})$$

Ct : Gas density, at a specific point (x, y, z), generated at the time "t".
Q (t): Amount of generated gas during the period from "t_{N-1}" to "t_N". (m^3/m^2)
h : Height of the gas generation source
u : Wind velocity (m/s)
R : Radius of liquid surface (m)
A : Diffusion parameter (m^2)

$$A = \frac{1}{(3.03)^2} \cdot qA\,(\rho A \cdot x + e^{-\rho A \cdot x} - 1)$$

B : Diffusion parameters

$$B = q_B\,(\rho_B \cdot x + e^{-\rho_B \cdot x} - 1)$$

erf (x) : Error function
Io (x) : O'th order first kind Bessel
ρ_A : Sakagami's meteorological parameter (1/m)
p_A : Sakagami's meteorological parameter (m^2)
ρ_B : Sakagami's meteorological parameter (1/m)
q_B : Sakagami's meteorological parameter (m^2)

(ii) Calculation Factor

i) Diffusion of Oil Surface and Gas of Crude Oil

Amount of momentary spill	1,000 (m^3)
Velocity gradient coefficient	0.1 (–)
Coefficient of Kinematic viscosity	0.1 (cm^2/s)
Gas transfer velocity	0.5 (m/s)
Rate of vaporization	13×10^{-4} ($gr/cm^3/min$)

Here, the percentage of the vaporization component of crude oil is assumed to be 5.5 percent.

The calculation is completed when the total amount of vaporization becomes 5.5 percent of the initial amount of the spill.

ii) Diffusion of Liquid Surface and Gas of LNG

Amount of momentary spill	1,000 (m^3)
LNG density (liquid)	465 (kg/m^3)
Rate of vaporization	4.23×10^{-4} (m/s)
Density of sea water	1,025 (kg/m^3)
Gas transfer velocity	0.5 (m/s)

iii) Diffusion of Liquid Surface and Gas of LPG

Amount of momentary spill	1,000 (m^3)
LPG density (liquid)	580 (kg/m^3)
Rate of vaporization	1.3 x 10^{-4} (m/s)
Density of sea water	1,025 (kg/m^3)
Gas transfer velocity	0.5 (m/s)

iv) Diffusion of LPG Gas as Conditioned by the Wind

Amount of momentary spill	1,000 (m^3)
LPG density (liquid)	580 (kg/m^3)
Rate of vaporization	1.3 x 10^{-4} (m/s)
Density of sea water	1,025 (kg/m^3)
Gas transfer velocity	3 (m/s)

3) Probable Amount of Oil Spilled

(i) In general, there are two types of accidents where a loaded oil tanker may sustain damage on its cargo tank and result in the release of oil. One is grounding and the other is collision with another vessel. The amount of oil spilled depends on location of damages and the size of loaded tank etc., and in case of collision scale of its damages depends on the speed of the vessel and in case of grounding it depends on the condition of the Canal bottom in addition to collision case.

It is necessary to quantity each element in order to determine the probable amount of spilled oil.

Currently available data, however, are limited to the relation between the size of the tanker and the spilled amount only, while other conditions such as vessel speed and location of damage could not easily be obtained.

Under the circumstances, following procedures are employed to obtain the probable amount of spilled oil.

(ii) Model Used

The probability of collision and grounding incidents have already been analysed, but the probability of oil spills resulting from collision and grounding of crude oil tankers is unavoidable because there are no sufficient statistical data to meet this purpose.

Therefore, the arithmetical average number is developed from the ratio of oil spill incidents against total number of collision and that against total number of grounding incidents.

As the amount of oil spilled depends on tanker size, and the location of damage, correlation between tanker size and the amount of spilled oil is calculated by applying least squares method.

Fig. V-2-(2)-8 shows the flow deriving the probable amount of oil spilled:

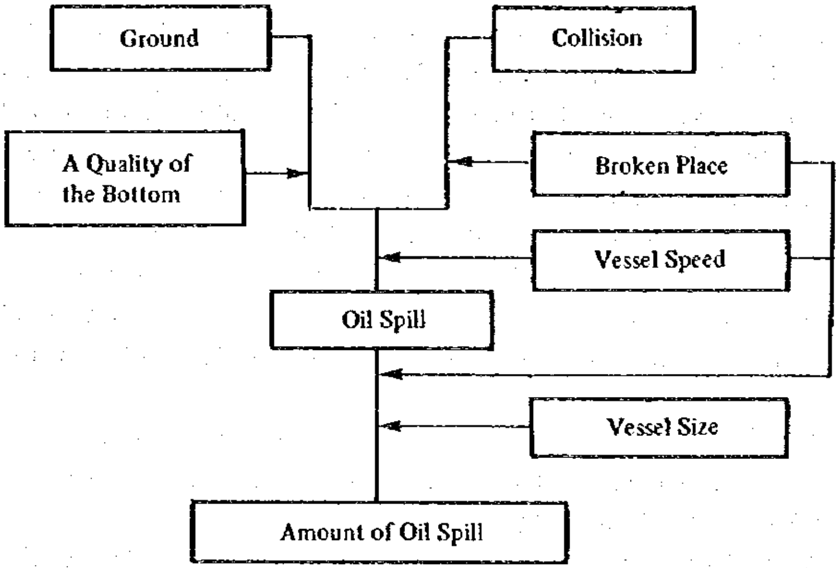


Fig. V-2-(2)-8 The Flow of Estimation of Amount of Oil Spill

i) Rate of occurrence of oil spill resulting from marine accidents (Collision and grounding):

Rate of occurrence is calculated on the basis of data of collision and grounding incidents in Japan from 1977 to 1982. The data are shown as follows:

Table V-2-(2)-4 Collisions in Crude Oil Tankers

	1977	1978	1979	1980	1981	1982	Total
All Collisions	14	14	5	27	9	11	80
Collisions with Oil Spill	7	1	5	11	2	4	30

Table V-2-(2)-5 Grounding in Crude Oil Tankers

	1977	1978	1979	1980	1981	1982	Total
All Groundings	33	32	30	31	26	20	172
Groundings with Oil Spill	4	1	1	3	4	3	16

$$\text{Rate of occurrence of oil spill in collisions } \left(\frac{\text{number of collision with oil spill}}{\text{number of all collision}}\right) = 0.375 \left(\frac{30}{80}\right)$$

$$\text{Rate of occurrence of oil spill in groundings } \left(\frac{\text{number of groundings with oil spill}}{\text{number of all groundings}}\right) = 0.0093 \left(\frac{16}{172}\right)$$

ii) Estimate of the amount of oil spilled in an accident (collision and Grounding):

All incidents handled by Japan Maritime Disaster Prevention Center from 1977 to 1983 are investigated, but numbers of collision and grounding were 9 and 2 cases respectively and are too few for our purpose, and data from "The Research on the Countermeasures for the Disasters Involving Very Large Tankers" published by the Japan Association for Preventing Marine Accidents are referenced.

We have 16 cases of collision but only 6 cases of grounding. As the 6 cases of grounding are still too small in number to estimate the amount of spilled oil, data source for the grounding incident is expanded to 1983 Lloyd's Tanker Casualty Bulletin.

As we assume that there is certain correlation between Gross Tonnage and Amount of oil spill, we plot them on a logarithmic section paper. The results are shown as Fig. V-2-(2)-9 and Fig. V-2-(2)-9.

We find correlation between them, and as we consider $Q = A \cdot K^b$ ($\log Q = \log a + b \log k$) as regression curve, we calculate "a" and "b" by method of least squares

Q: Amount of oil spill

K: Tanker Size

Q (collision) $= 0.018 \cdot K^{1.19}$ or $K = 28.5 \cdot Q^{0.838}$

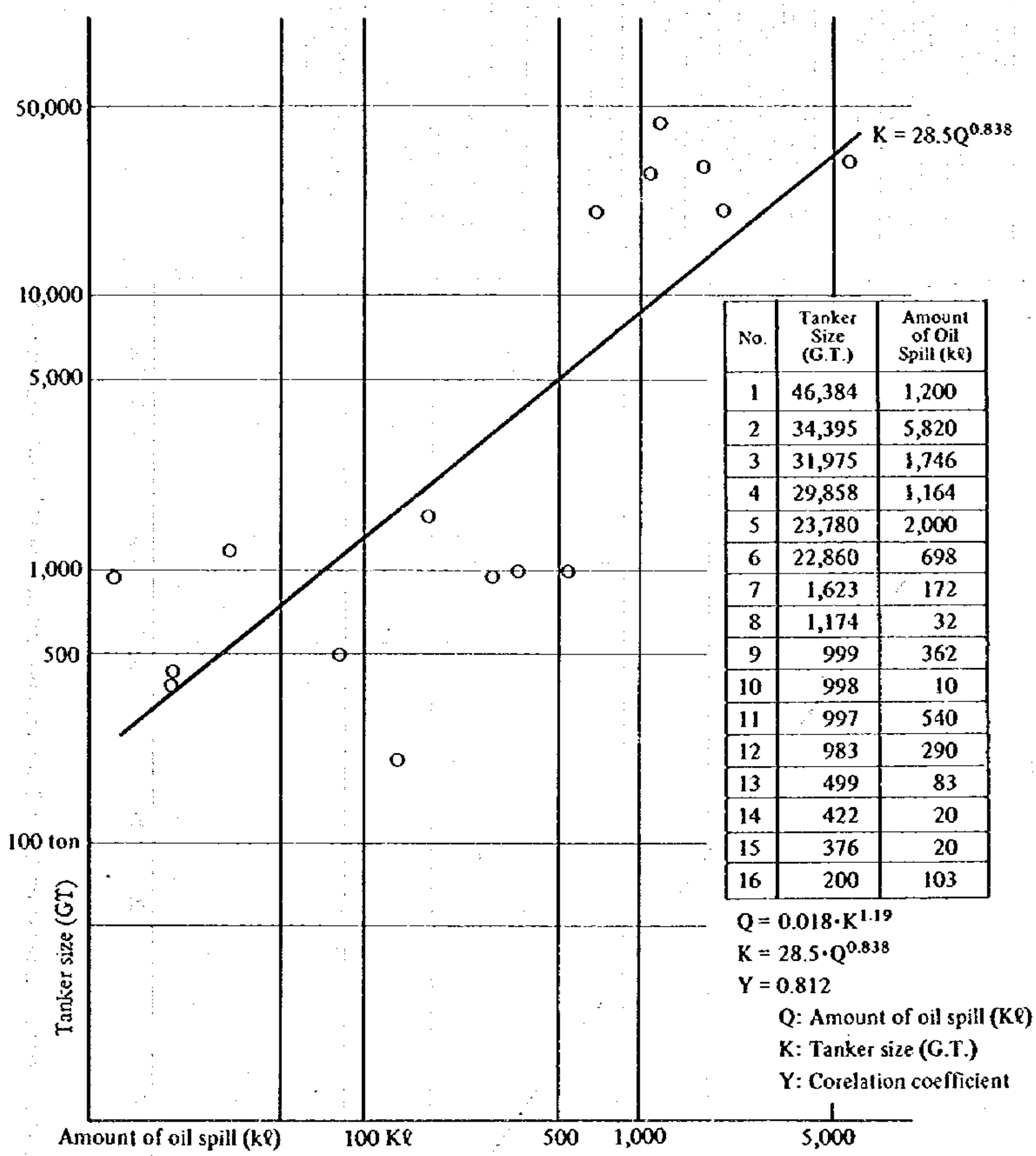
Q (ground) $= 0.0018 \cdot K^{1.41}$ or $K = 89.89 \cdot Q^{0.710}$

Correlation coefficient in collision and ground are 0.812 and 0.797 respectively.

However, all oil spills which occurred in the Suez Canal has so far resulted from grounding and data are scarce for analyzing probable spill in this area.

Under the circumstances, we are obliged to expand the data source to those of worldwide whereby we must admit that consideration to the special character of Suez Canal, such as speed restriction, one way traffic system in convoy, sand bottom, etc. are not reflected in the above formula.

It is, therefore, necessary to take into account foregoing limitations when the above formula is applied to the calculation of probable amount of spilled oil in Suez Canal area.



No.	Tanker Size (G.T.)	Amount of Oil Spill (kℓ)
1	46,384	1,200
2	34,395	5,820
3	31,975	1,746
4	29,858	1,164
5	23,780	2,000
6	22,860	698
7	1,623	172
8	1,174	32
9	999	362
10	998	10
11	997	540
12	983	290
13	499	83
14	422	20
15	376	20
16	200	103

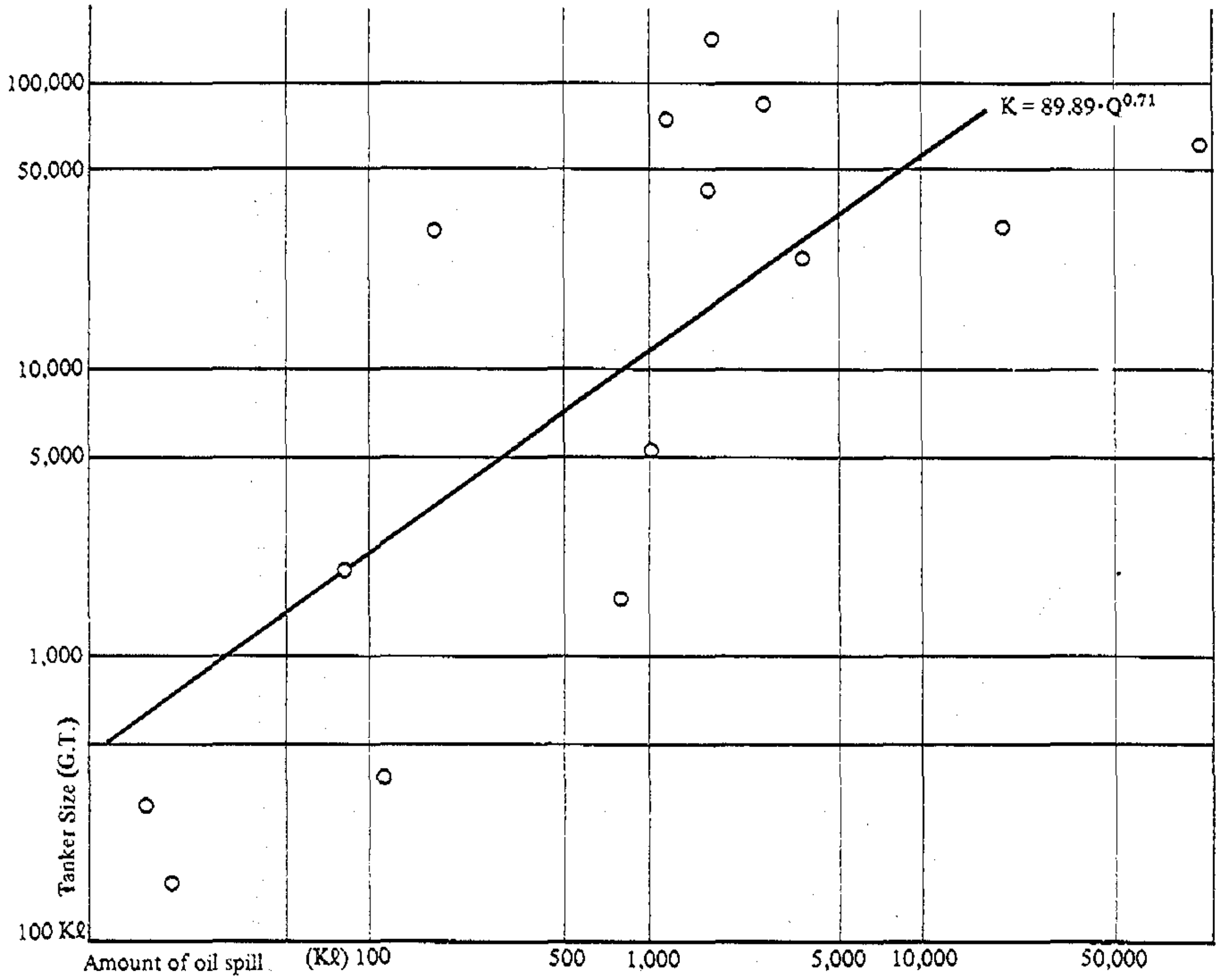
$Q = 0.018 \cdot K^{1.19}$

$K = 28.5 \cdot Q^{0.838}$

$Y = 0.812$

Q: Amount of oil spill (Kℓ)
K: Tanker size (G.T.)
Y: Corelation coefficient

Fig. V-2-(2)-9 Corelation between Gross Tonnage and Amount of Oil Spill in Collision



No.	Tanker Size (G.T.)	Amount of Oil Spill (kℓ)
1	153,610	1,590
2	83,819	2,421
3	75,272	1,145
4	61,261	93,131
5	44,331	1,630
6	31,720	18,626
7	29,660	159
8	24,825	3,490
9	5,279	984
10	2,996	795
11	1,975	80
12	370	114
13	199	6
14	161	10

$Q = 0.0018K^{1.41}$

$K = 89.89Q^{0.71}$

$Y = 0.797$

Q: Amount of oil spill (Kℓ)

K: Tanker Size (G.T.)

Y: Corelation coefficient

Fig. V-2-(2)-10 Corelation between Gross Tonnage and Amount of Oil Spill in Grounding

(iii) Estimation Results of Oil Spill Probability

The established model in (i) gives the probability of oil spill of a certain amount based on specified parameters in (ii) and the probability of accident causing the leakage.

The procedure to obtain the probability of oil of a certain amount (Defined as a number of times per transit) is as follow.

i) Specification of spill amount of oil (Q)

The following 3 cases have been taken for this study.

① 0 ~ 10,000 (t)
② 10,000 ~ 20,000 (t)
③ 20,000 ~

ii) Corresponding range of ship size (K)

Integration ranges for P_v (k) in (ii) such as $K_1 \sim K_2$, $K_1 \sim K_3$, $K_2 \sim K_3$ are specified based on above the spill amount of oil. To obtain K, the relationships between K and Q identified above (ii) is used.

(In case of grounding . . . . . $K = 89.89 \times Q^{0.71}$)
① 0 ~ 62,000 DWT (0 ~ 10,000 (t))
② 62,000 ~ 102,000 DWT (10,000 ~ 20,000 (t))
③ 102,000 DWT ~ (20,000 (t) ~)

(In case of collision . . . . $K = 28.5 \times Q^{0.838}$)
① 0 ~ 64,000 DWT (0 ~ 10,000 (t))
② 64,000 ~ 115,000 DWT (10,000 ~ 20,000 (t))
③ 115,000 DWT ~ (20,000 (t) ~)

iii) Spill probability (P_{SG}, P_{SC})

The probability that an oil leaks more or less when accidents happen have been obtained in (ii) by using observed data as follow.

(In case of Grounding) . . . . $P_{SG} = 0.093$
(In case of Collision) . . . . $P_{SC} = 0.375$

iv) Proportion of size distribution

Since accident probabilities are constant in the range set above in ii), the proportion between K_1 and K_2 in size distribution $\int_{K_1}^{K_2} P_v(k)dk$ is used.

v) Oil loading probability

It is necessary to multiply the oil loading probability with the oil spill probability, because the probability is defined as the number of times per transit. The oil loading probability is obtained by the following equation.

(A proportion of tanker among all vessel) x (Loading probability of tanker by size range)
The observed transit data in 1982 are available for the above equation. (Interium Report (I), pp. 121–122).

vi) Calculation

These data i) ~ v) and accident probabilities are subsituted into the model in (ii), then the probability of oil spill for a certain amount is obtained by accident type,

① Grounding
② Rear End Collision
③ Collision between vessels

and by development phase.

① At present
② After Second Stage Development Project

Table V-2-(2)-6, V-2-(2)-7 and V-2-(2)-8 show the obtained results.

Table V-2-(2)-6 Probability of A Certain Amount of Oil Spill (By Grounding)

Spill Amount (Q: t) / Necessary Data	0 ~ 10,000	10,000 ~ 20,000	20,000 ~
Ship Size Range (K, DWT)	0 ~ 62,000	62,000 ~ 102,000	102,000 ~
Representative Size (K, DWT)	38,000	83,000	136,000
Spill Probability (P_{SC})	0.093	0.093	0.093
Size Proportion $\int_{K_1}^{K_2} P_v(k)dk$	0.648	0.272	0.08
Oil Loading Probability (Pt)	0.089	0.140	0.149
Accident Probability At Present After Second Stage Development Project	 1.96×10^{-3} 0.59×10^{-3}	 1.96×10^{-3} 0.70×10^{-3}	 1.96×10^{-6} 0.70×10^{-6}
Probability of Oil Spill of A Certain Amount At Present After Second Stage Development Project	 1.05×10^{-5} 0.31×10^{-5}	 6.94×10^{-6} 2.48×10^{-6}	 2.17×10^{-6} 0.76×10^{-6}

Table V-2-(2)-7 Probability of A Certain Amount of Oil Spill (By Rear End Collision)

Spill Amount (Q: t) / Necessary Data	0 ~ 10,000	10,000 ~ 20,000	20,000 ~
Ship Size Range (K, DWT)	0 ~ 64,000	64,000 ~ 115,000	115,000 ~
Representative Size (K, DWT)	36,000	90,000	161,000
Spill Probability (P_{SC})	0.375	0.375	0.375
Size Proportion $\int_{K_1}^{K_2} P_v(k)dk$	0.659	0.222	0.119
Oil Loading Probability (Pt)	0.089	0.140	0.149
Accident Probability At Present After Second Stage Development Project	 0.34×10^{-3} 0.68×10^{-4}	 0.15×10^{-5} 0.55×10^{-6}	 0.15×10^{-5} 0.55×10^{-6}
Probability of Oil Spill of A Certain Amount At Present After Second Stage Development Project	 7.48×10^{-6} 1.49×10^{-6}	 1.75×10^{-8} 0.64×10^{-8}	 9.97×10^{-9} 3.65×10^{-9}

Table V-2-(2)-8 Probability of A Certain Amount of Oil Spill (By Collision between Vessels)

Spill Amount (Q: t) Necessary Data	0 ~10,000	10,000 ~ 20,000	20,000 ~
Ship Size Range (K, DWT)	0 ~ 64,000	64,000 ~ 115,000	115,000 ~
Representative Size (K, DWT)	36,000	90,000	161,000
Spill Probability (P_{SC})	0.375	0.375	0.375
Size Proportion $\int_{K_1}^{K_2} P_v(k)dk$	0.659	0.222	0.119
Oil Loading Probability (Pt)	0.089	0.140	0.149
Accident Probability			
At Present			
Junction (Km 61)	4.55×10^{-7}	4.55×10^{-7}	3.26×10^{-7}
Junction ((Km 94)	6.77×10^{-7}	6.77×10^{-7}	4.33×10^{-7}
Junction (Km 123)	0.25×10^{-7}	0.23×10^{-7}	0.23×10^{-7}
Two Way Pass (S.L.)	2.67×10^{-4}	2.67×10^{-4}	2.61×10^{-4}
Two Way Pass (N.L. ~ S.L.)	2.16×10^{-4}	2.16×10^{-4}	2.12×10^{-4}
Two Way Pass (Hm. 80)	4.25×10^{-4}	4.25×10^{-4}	4.16×10^{-4}
Waiting Area (Port Said)	4.04×10^{-5}	3.90×10^{-5}	3.90×10^{-5}
Waiting Area (Great Bitter Laka)	8.11×10^{-5}	8.09×10^{-5}	8.09×10^{-5}
After Second Stage Development Project			
Junction (Km 61)	2.95×10^{-7}	2.95×10^{-7}	2.11×10^{-7}
Junction (Km 94)	4.39×10^{-7}	4.39×10^{-7}	2.81×10^{-7}
Junction (Km 123)	0.16×10^{-7}	0.16×10^{-7}	0.15×10^{-7}
Two Way Pass (S.L.)	2.67×10^{-4}	2.67×10^{-4}	2.61×10^{-4}
Two Way Pass (N.L. ~ S.L.)	2.16×10^{-4}	2.16×10^{-4}	2.12×10^{-4}
Two Way Pass (Hm. 80)	4.25×10^{-4}	4.25×10^{-4}	4.16×10^{-4}
Waiting Area (Port Said)	4.04×10^{-5}	3.90×10^{-5}	3.90×10^{-5}
Waiting Area (Great Bitter Lake)	8.11×10^{-5}	8.09×10^{-5}	8.09×10^{-5}
Probability of Oil Spill of A Certain Amount			
At Present			
Junction (Km 61)	1.00×10^{-8}	5.32×10^{-9}	2.16×10^{-9}
Junction (Km 94)	1.48×10^{-8}	7.92×10^{-9}	2.88×10^{-9}
Junction (Km 123)	0.55×10^{-9}	0.26×10^{-9}	1.53×10^{-9}
Two Way Pass (S.L.)	5.87×10^{-6}	3.12×10^{-6}	1.74×10^{-6}
Two Way Pass (N.L. ~ S.L.)	4.74×10^{-6}	2.52×10^{-6}	1.41×10^{-6}
Two Way Pass (Hm. 80)	9.34×10^{-6}	4.97×10^{-6}	2.77×10^{-6}
Waiting Area (Port Said)	8.88×10^{-7}	4.56×10^{-7}	2.59×10^{-7}
Waiting Area (Great Bitter Lake)	1.73×10^{-6}	9.47×10^{-7}	5.38×10^{-7}
After Second Stage Development Project			
Junction (Km 61)	6.49×10^{-9}	3.45×10^{-9}	1.40×10^{-9}
Junction (Km 94)	9.54×10^{-9}	5.13×10^{-9}	1.87×10^{-9}
Junction (Km 123)	0.35×10^{-9}	0.18×10^{-9}	1.00×10^{-10}
Two Way Pass (S.L.)	5.87×10^{-6}	3.12×10^{-6}	1.74×10^{-6}
Two Way Pass (N.L. ~ S.L.)	4.74×10^{-6}	2.52×10^{-6}	1.41×10^{-6}
Two Way Pass (Hm. 80)	9.34×10^{-6}	4.97×10^{-6}	2.77×10^{-6}
Waiting Area (Port Said)	8.88×10^{-7}	4.56×10^{-7}	2.59×10^{-7}
Waiting Area (Great Bitter Lake)	1.73×10^{-6}	9.47×10^{-7}	5.38×10^{-7}

4) Trial Calculation of Spreading of Crude oil at Port Said, Great Bitter Lake, and Suez Bay Respectively.

(i) Hypothetical Accidents

The hypothetical accidents are shown in Table V-2-(2)-9 below.

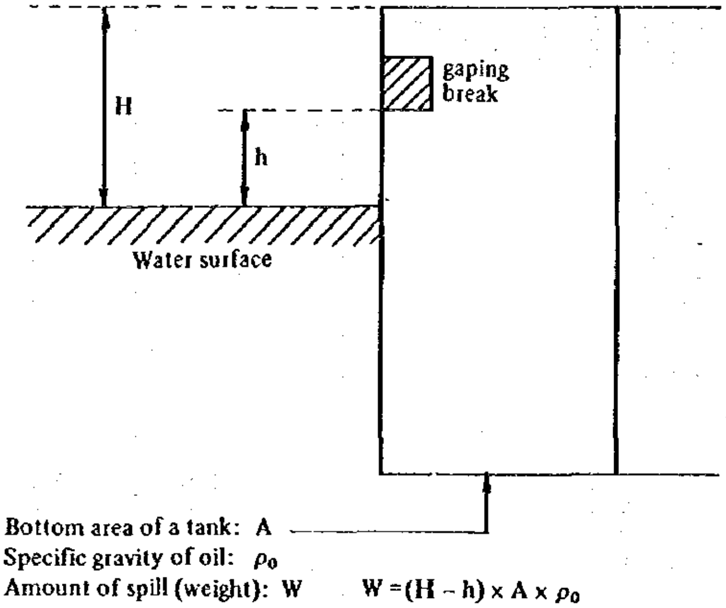
Table V-2-(2)-9 Hypothetical Accidents

Day and Time Accident (collision)	Meteorology	Colliding Ship	Place of Collision	Ship Part Involved in Collision	Extent of Damage
X'th Day 06:00	Cloudy Wind NNW 8 m/s	Northbound, half-loaded crude oil tanker (260,158 DWT) Northbound, General Cargo Vessel (20,000 DWT)	Suez Bay, West of Conry Rock, Vicinity: 29°-48'.6N 32°-33'.2E	The bow of the cargo boat collided with the third tank (24,831 m^3, fully loaded) of the half-loaded crude oil tanker	A.A gaping break of 5 m^2 was made in the side wall of the tank, 7.6 m above the water line. B.A gaping break of 10 m^2 was made in the side wall of the tank, 1.6 m above the water line. C.A gaping break of 5 m^2 was made in the side wall of the tank, 6 m above the water line, and another gaping break of 10 m^2 was made in the side wall of the tank, 1.36 m below the water line.
Y'th Day 11:00	Cloudy Wind N 8 m/s	Northbound, half-loaded crude oil tanker (260,158 DWT) Southbound, General Cargo Vessel (20,000 DWT)	Great Bitter Lake, South southeast of North Light Vicinity: 30°-21'.1N 32°-22'.5E	ditto	ditto
Z'th Day 17:00	Cloudy Wind N 8 m/s	Northbound, half-loaded crude oil tanker (260,158 DWT) Southbound, General Cargo Vessel (20,000 DWT)	Port Said Vicinity: 31°-19'.6N 32°-22'.3E	ditto	ditto

(ii) Estimation of the Spilled Amount of Oil Cargo

i) Method of Calculation

(a) Method of calculation of the spilled amount when a gaping break is above the water surface.



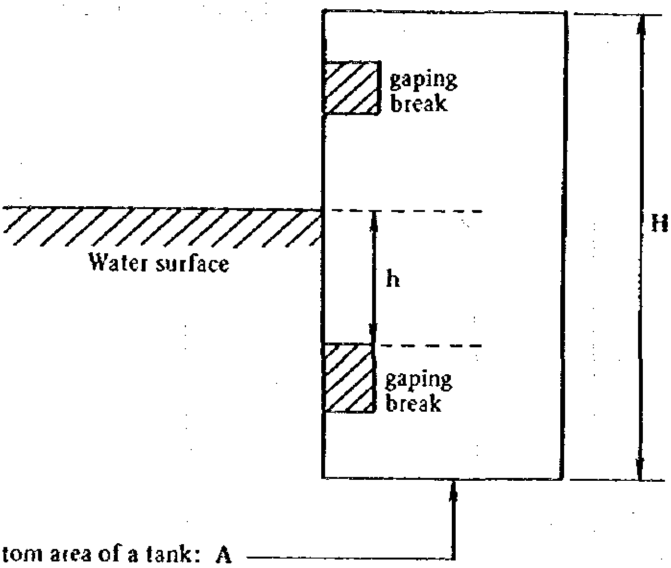
Bottom area of a tank: A

Specific gravity of oil: ρ_0

Amount of spill (weight): W $W = (H - h) \times A \times \rho_0$

Fig. V-2-(2)-11 A Gaping Break above the Water Surface

(b) Method of calculation of the spilled amount when the gaping breaks are above and below the water surface.



Bottom area of a tank: A

Specific gravity of oil: ρ_o

Amount of spill (weight): W

Specific gravity of sea water: ρw

$$W = H \times A \times \rho_o - h \times A \times \rho w$$

Fig. V-2-(2)-12 Gaping Breaks above and below the Water Surface

ii) Calculation

(a) Basis of Calculation

The basis of calculation, as assumed, is shown in Fig. V-2-(2)-13 according to the hypothetical accidents listed in Table V-2-(2)-9.

Here, the relative situations of the hypothetical accidents, A, B, C, are shown in Fig. V-2-(2)-14.

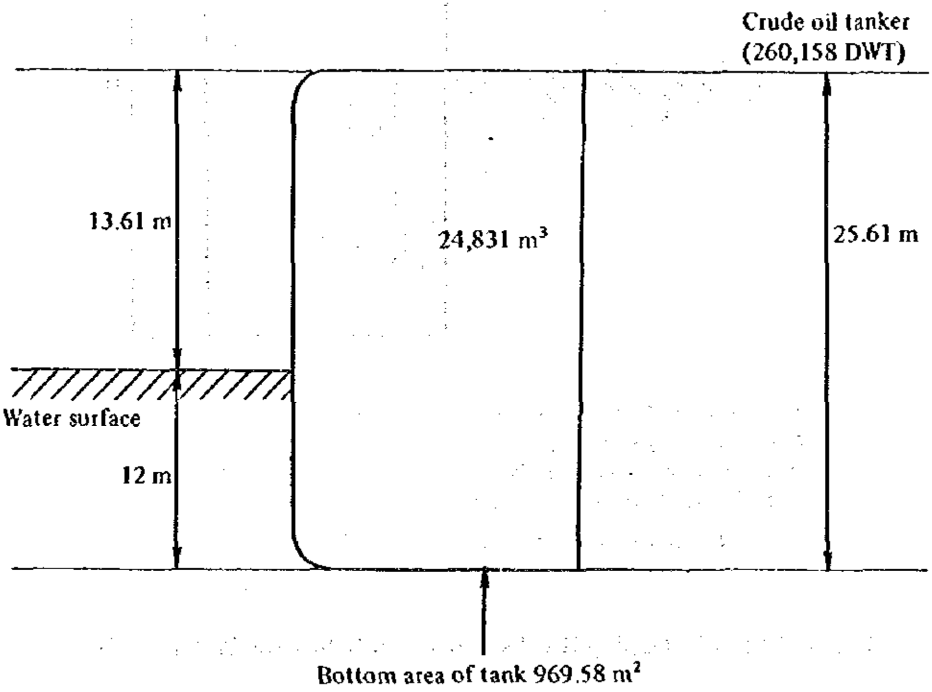
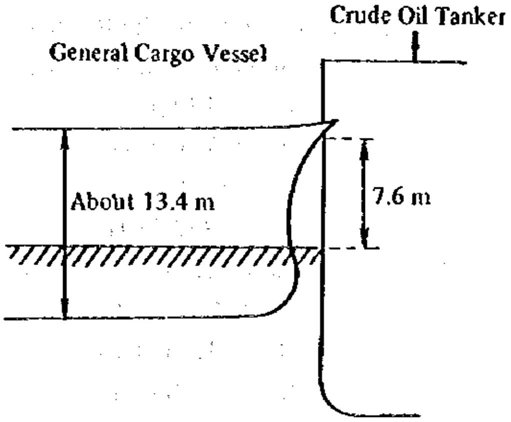
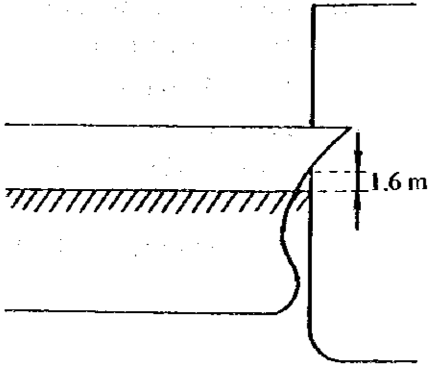


Fig. V-2-(2)-13 The Size of the Tank of the Crude Oil Tanker involved in the Accident

Hypothetical accident: A
General Cargo Vessel: 20,000 DWT class
Half-loaded condition



Hypothetical accident: B
General Cargo Vessel: 20,000 DWT class
Fully loaded



Hypothetical accident: C
General Cargo Vessel: 20,000 DWT class
Collision of the spherical part of
the bow below the water surface

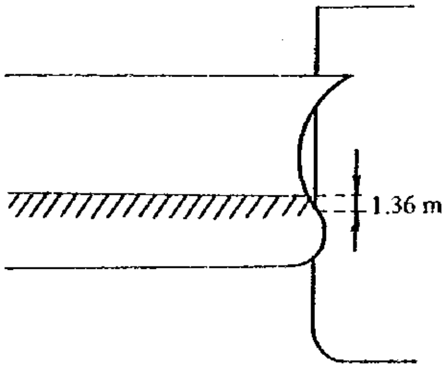


Fig. V-2-(2)-14 Hypothetical Accidents

(b) Calculation and the Results

a) Spilled amount in case of the hypothetical accident "A"

$H = 13.6$ (m)
$h = 7.60$ (m)
$\rho_o = 0.86$
$A = 969.58$ (m^2)
Amount of the spill: $W = (13.61 - 7.60) \times 969.58 \times 0.86 \fallingdotseq 5{,}000$ tons

b) Spilled amount in case of the hypothetical accident "B"

$H = 13.61$ (m)
$h = 1.60$ (m)
$\rho_o = 0.86$
$A = 969.58$ (m^2)
Amount of the spill: $W = (13.61 - 1.60) \times 969.58 \times 0.86 \fallingdotseq 10{,}000$ tons

c) Spilled amount in case of the hypothetical accident "C"

$H = 25.61$ (m)
$h = 1.36$ (m)
$\rho_o = 0.86$
$\rho w = 1.025$
$A = 969.58$ (m^2)
Amount of the spill: $W = 25.61 \times 969.58 \times 0.86 - 1.36 \times 969.58 \times 1.025 \fallingdotseq 20{,}000$ tons

(iii) Calculation of the Spread of Spilled Crude Oil

Sketches of the calculated results are as follows:

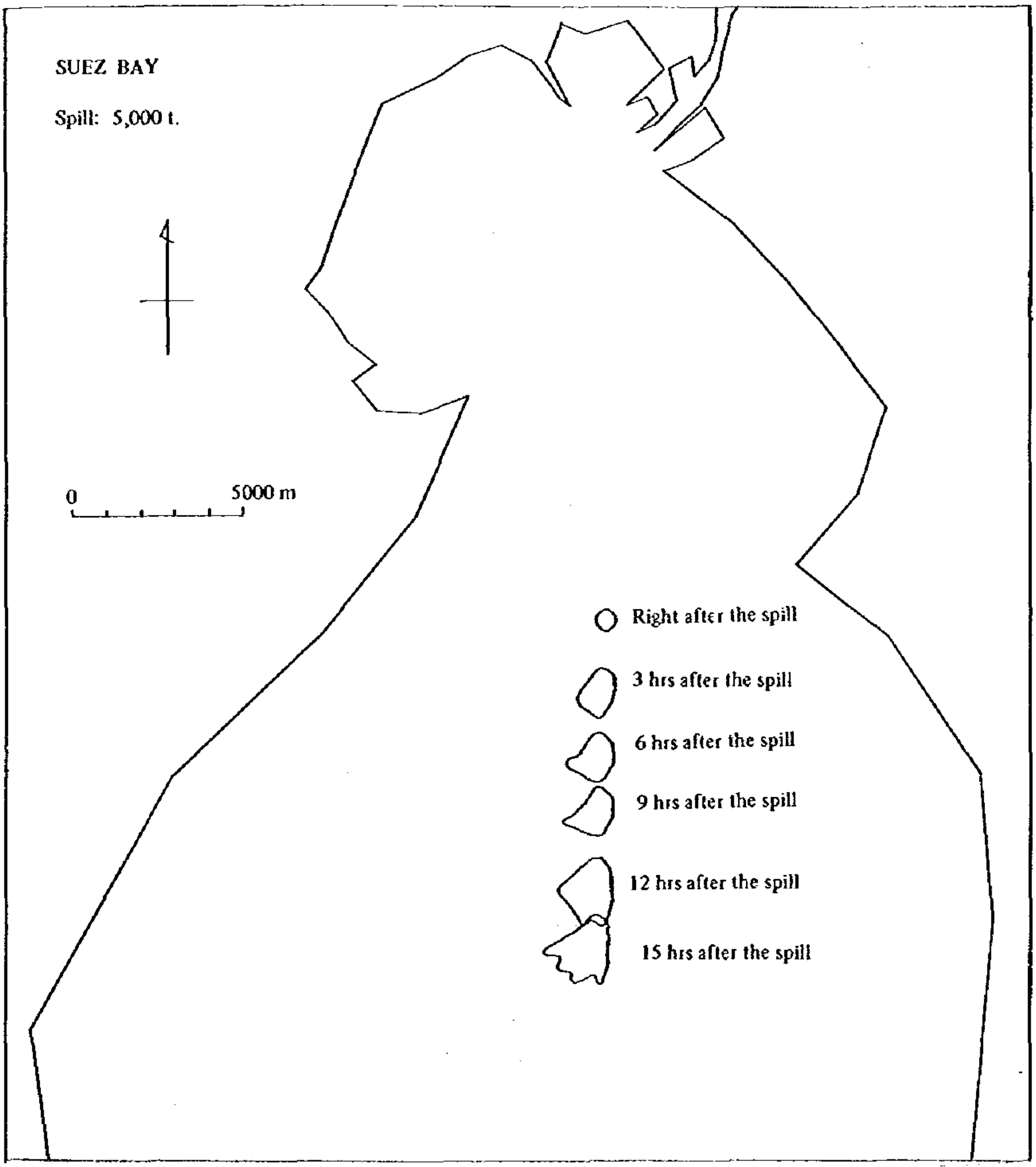
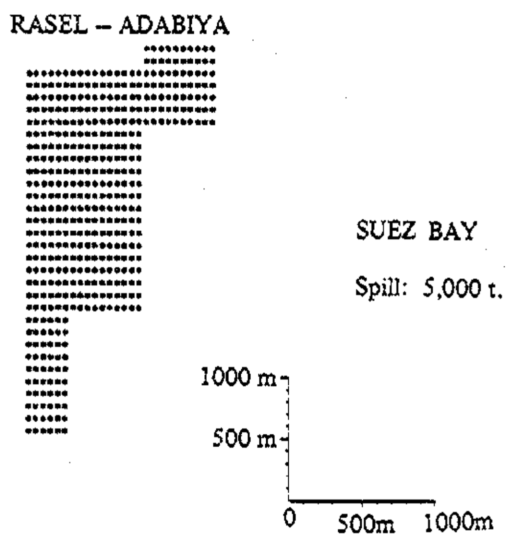


Fig. V-2-(2)-15 The Spreading of 5,000 tons of Crude Oil in Suez Bay



Slick thickness	Designation
Less than 0.5 mm	1
0.5 ~ 1.0 mm	2
1.0 ~ 1.5	3
1.5 ~ 2.0	4
2.0 ~ 2.5	5
2.5 ~ 3.0	6
3.0 ~ 3.5	7
3.5 ~ 4.0	8
More than 4.0 mm	9
Land	*

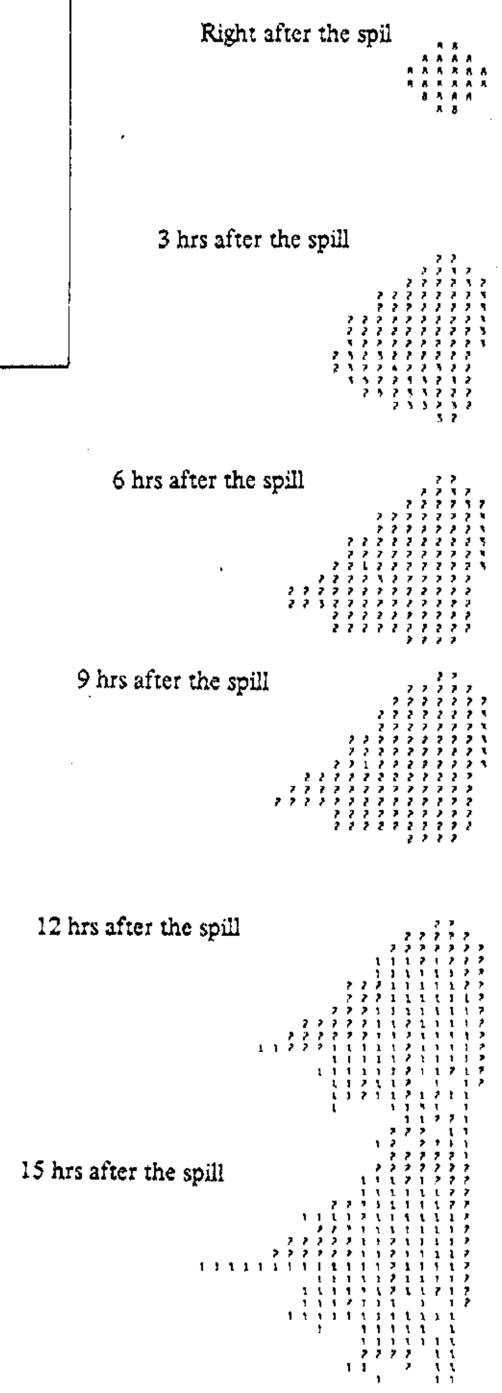


Fig. V-2-(2)-16 An Enlarged Display of the Spreading of 5,000 tons of Crude Oil in Suez Bay

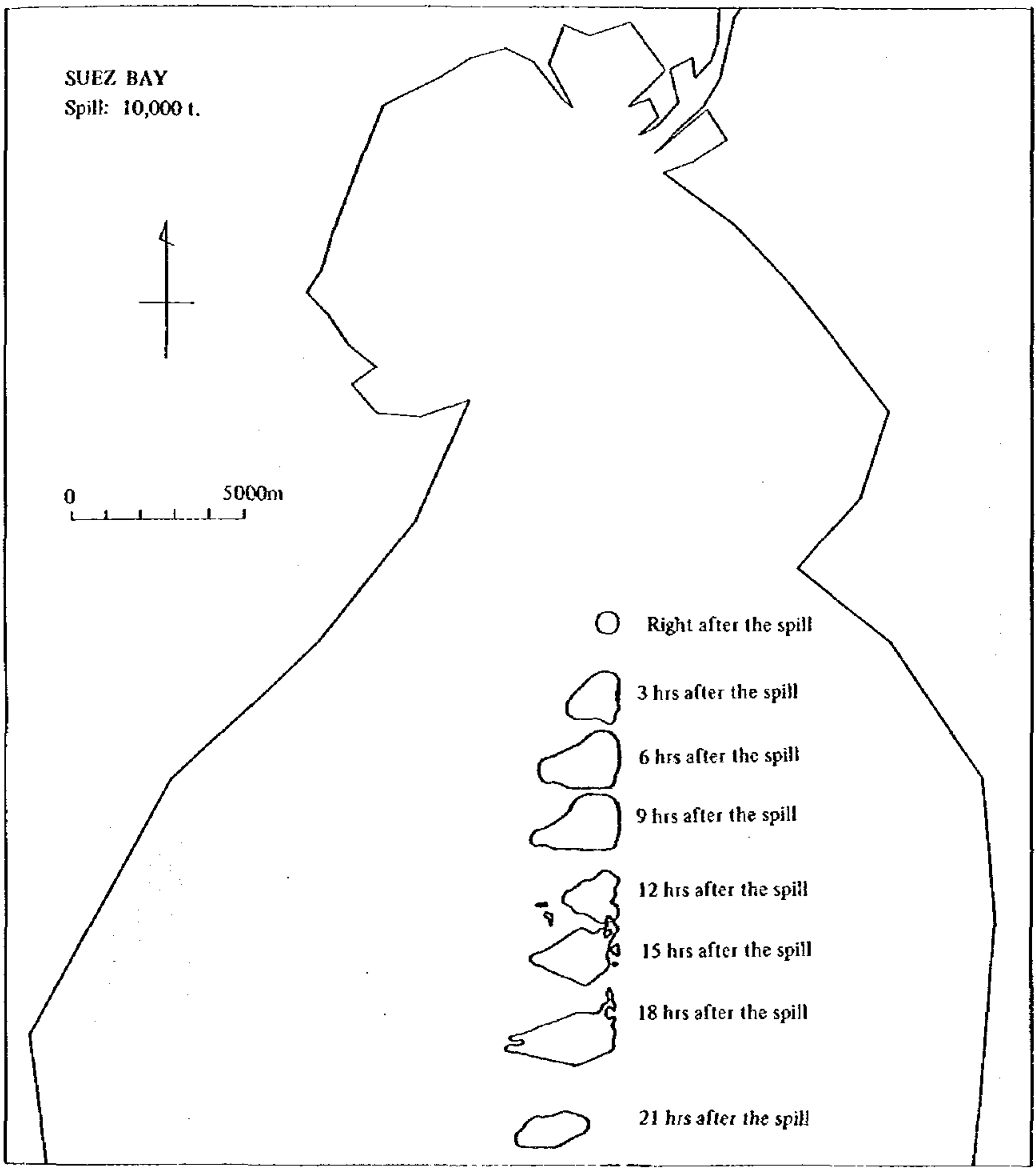
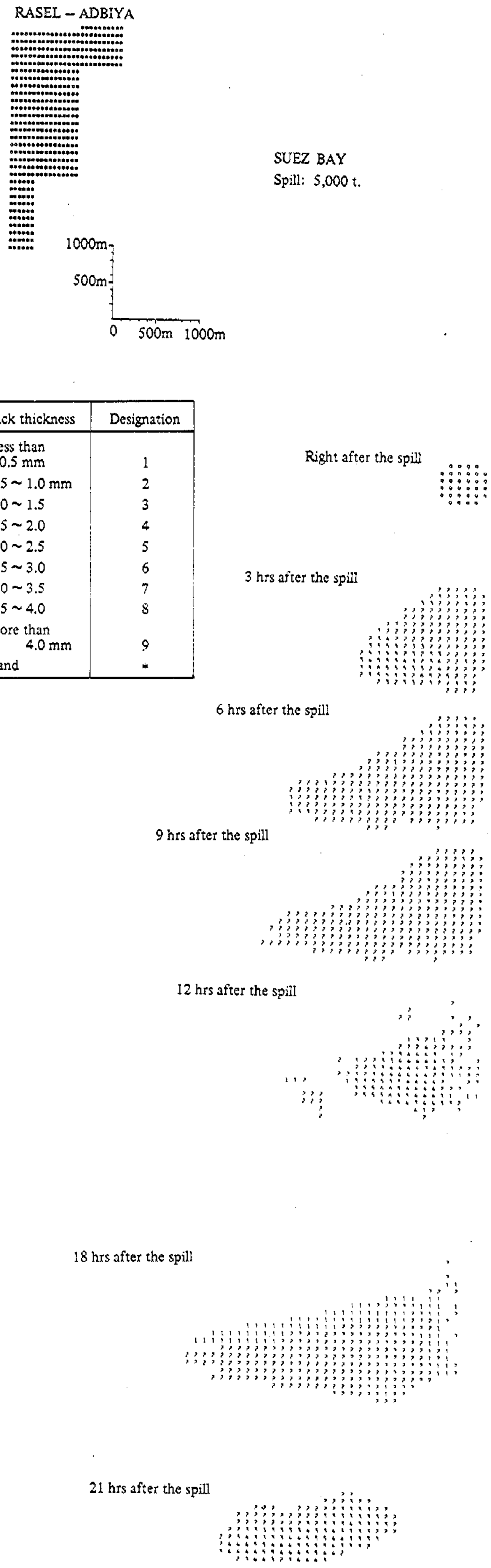


Fig. V-2-(2)-17 The Spreading of 10,000 tons of Crude Oil in Suez Bay



Slick thickness	Designation
Less than 0.5 mm	1
0.5 ~ 1.0 mm	2
1.0 ~ 1.5	3
1.5 ~ 2.0	4
2.0 ~ 2.5	5
2.5 ~ 3.0	6
3.0 ~ 3.5	7
3.5 ~ 4.0	8
More than 4.0 mm	9
Land	*

Fig. V-2-(2)-18 An Enlarged Display of the Spreading of 10,000 tons of Crude Oil in Suez Bay

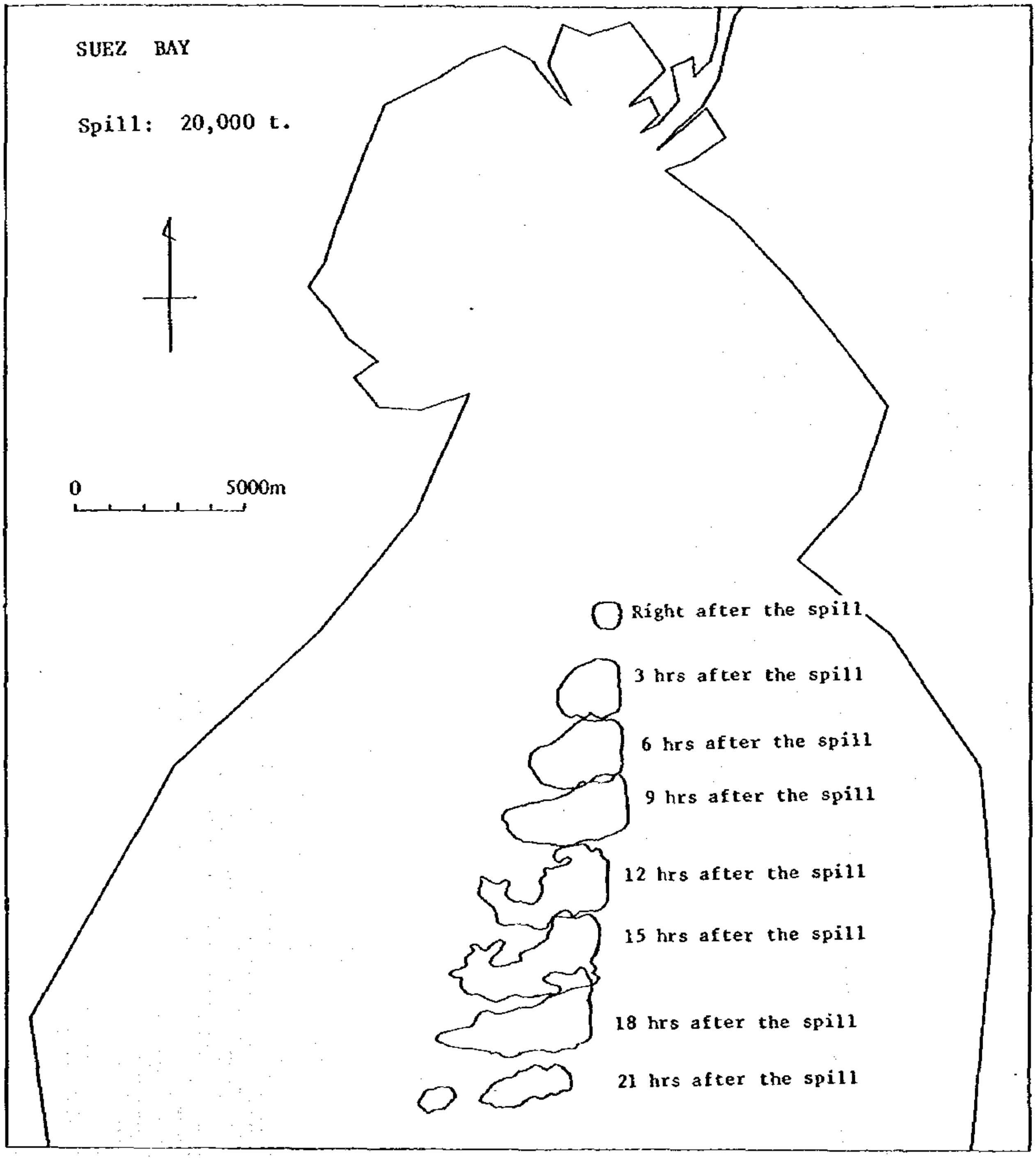
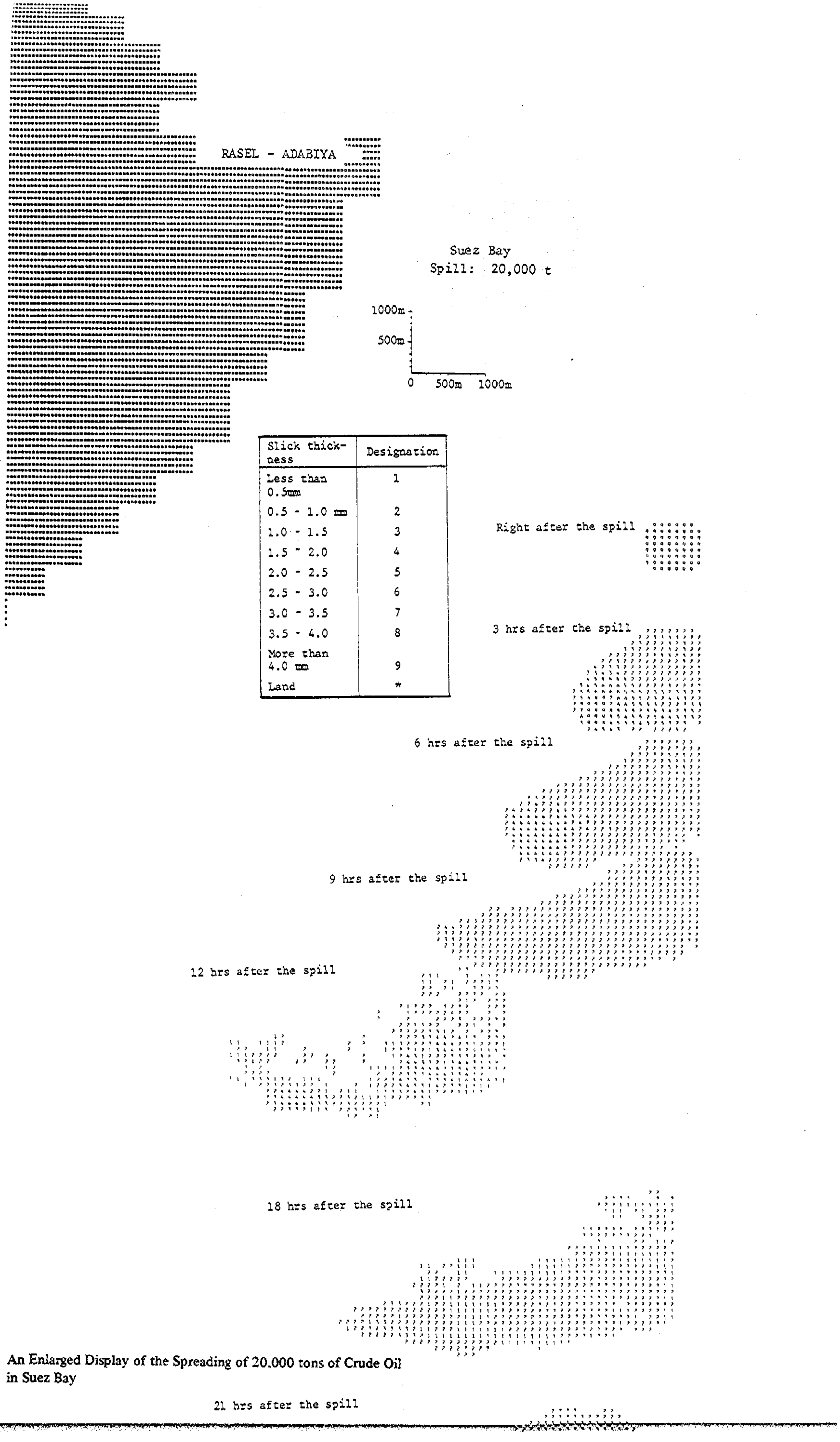
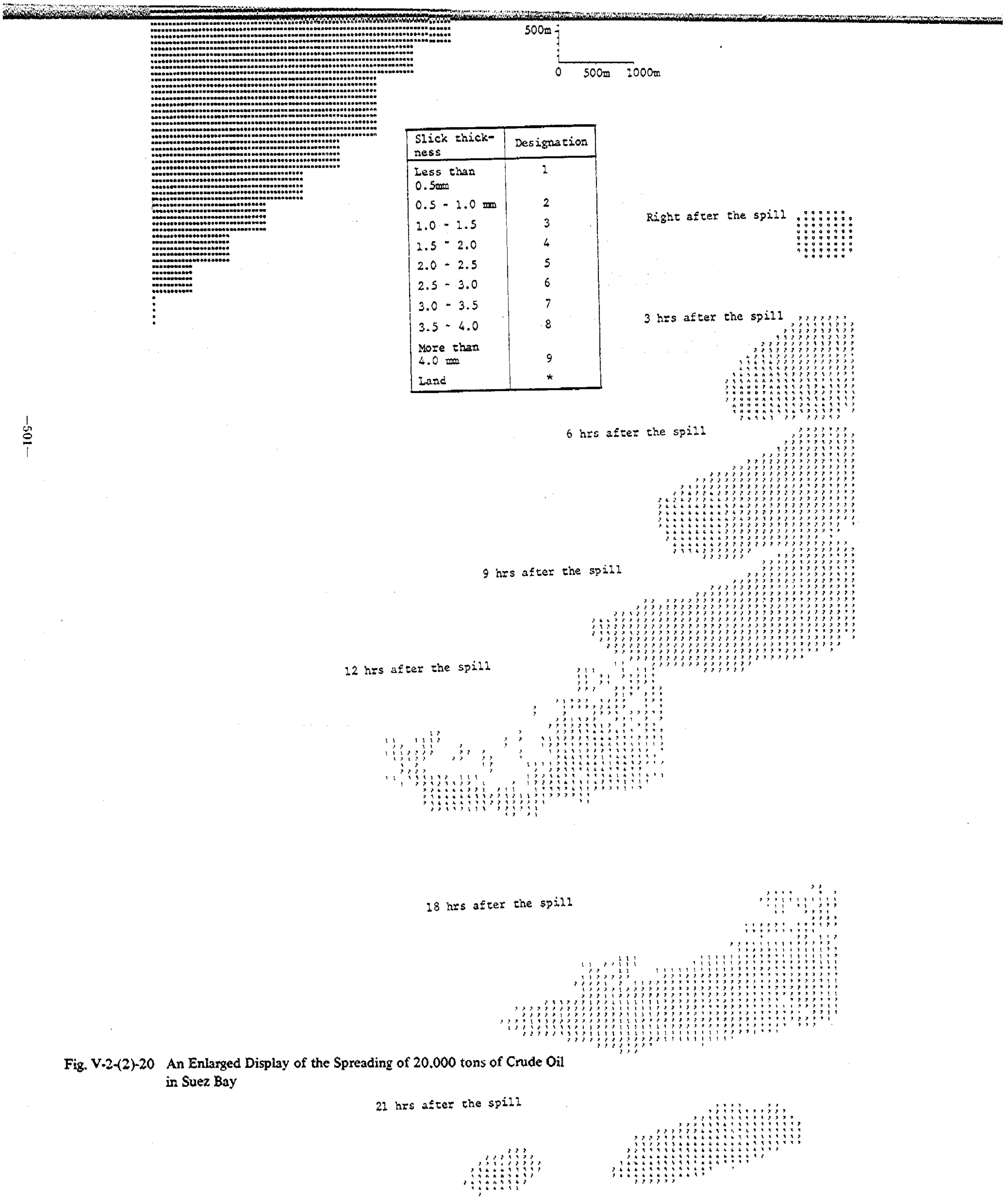


Fig. V-2-(2)-19 The Spreading of 20,000 tons of Crude Oil in Suez Bay



Slick thick-ness	Designation
Less than 0.5mm	1
0.5 - 1.0 mm	2
1.0 - 1.5	3
1.5 - 2.0	4
2.0 - 2.5	5
2.5 - 3.0	6
3.0 - 3.5	7
3.5 - 4.0	8
More than 4.0 mm	9
Land	*

Fig. V-2-(2)-20 An Enlarged Display of the Spreading of 20,000 tons of Crude Oil in Suez Bay



Slick thickness	Designation
Less than 0.5mm	1
0.5 - 1.0 mm	2
1.0 - 1.5	3
1.5 - 2.0	4
2.0 - 2.5	5
2.5 - 3.0	6
3.0 - 3.5	7
3.5 - 4.0	8
More than 4.0 mm	9
Land	*

Fig. V-2-(2)-20 An Enlarged Display of the Spreading of 20,000 tons of Crude Oil in Suez Bay

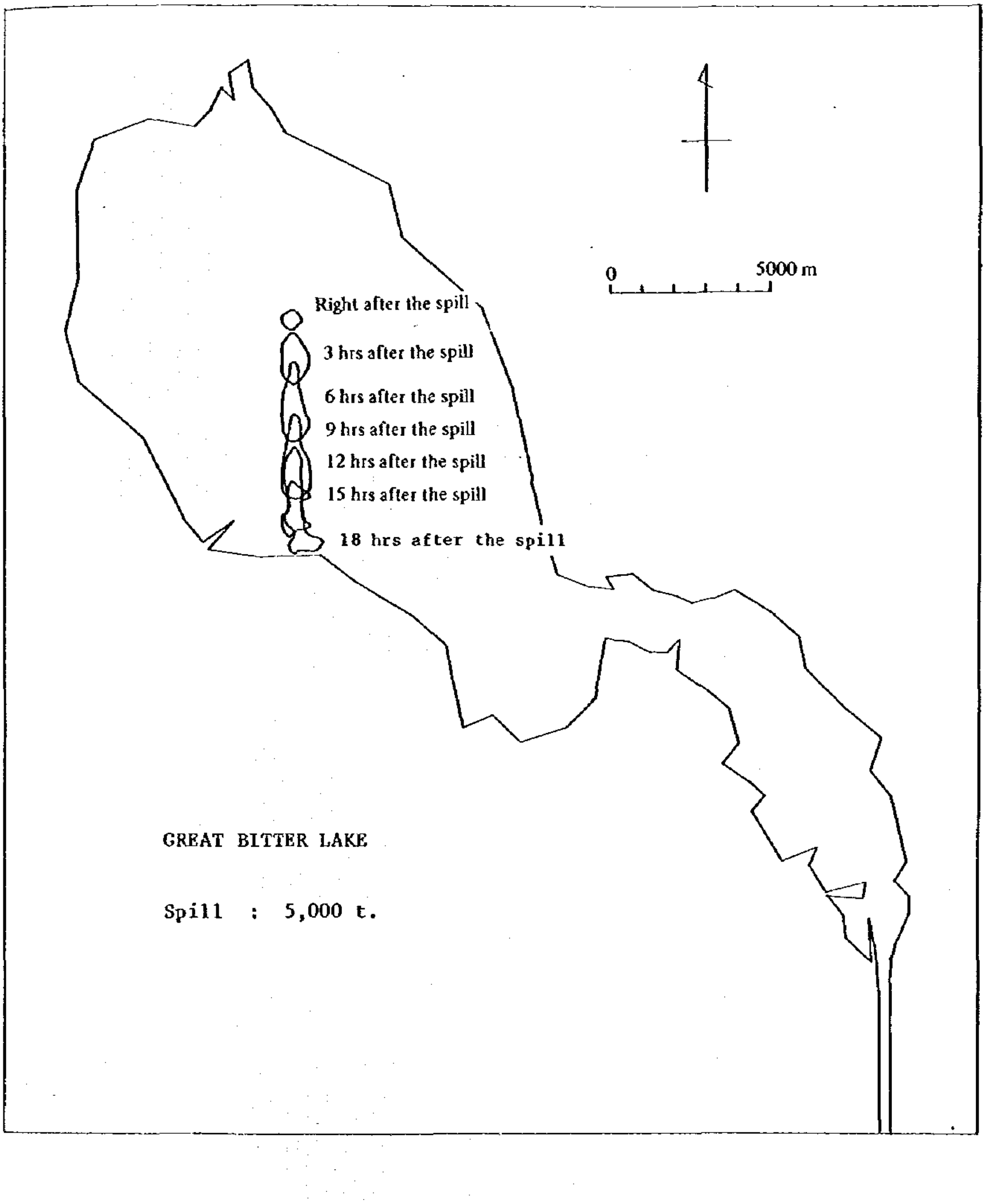
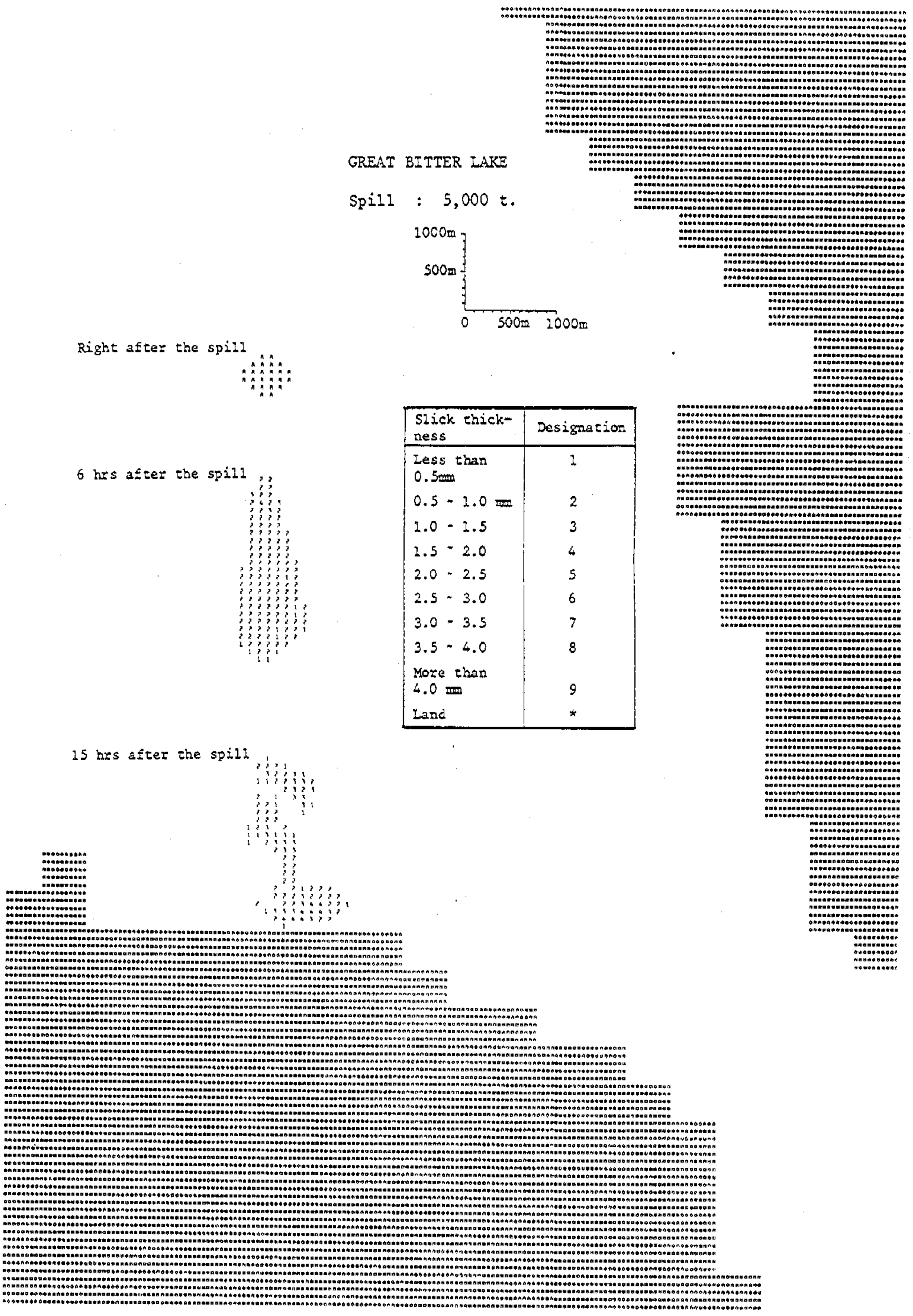


Fig. V-2-(2)-21 The Spreading of 5,000 tons of Crude Oil in Great Bitter Lake



Slick thickness	Designation
Less than 0.5mm	1
0.5 ~ 1.0 mm	2
1.0 - 1.5	3
1.5 ~ 2.0	4
2.0 ~ 2.5	5
2.5 ~ 3.0	6
3.0 - 3.5	7
3.5 ~ 4.0	8
More than 4.0 mm	9
Land	*

Fig. V-2-(2)-22 An Enlarged Display of the Spreading of 5,000 tons of Cruide Oil in Great Bitter Lake

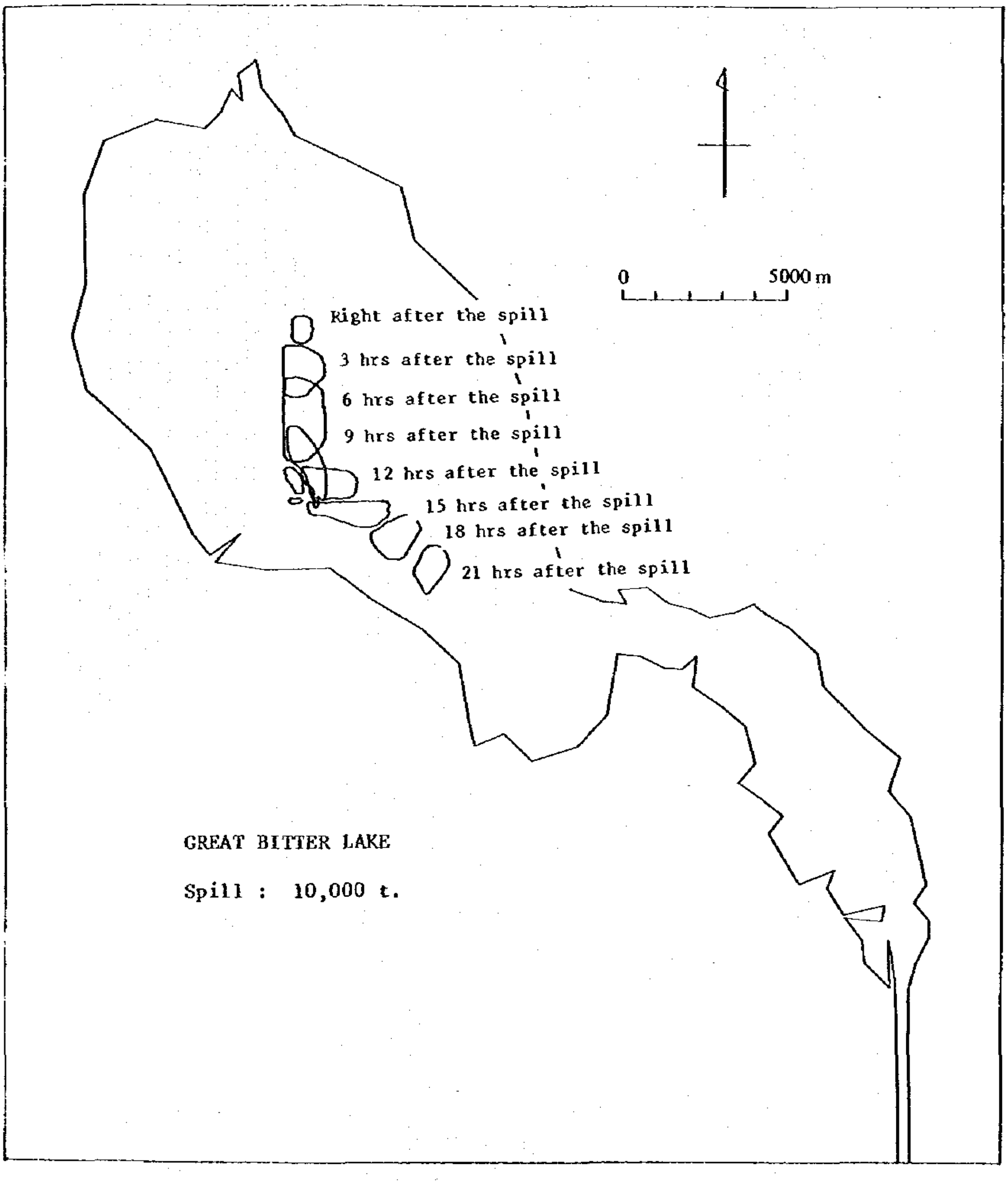
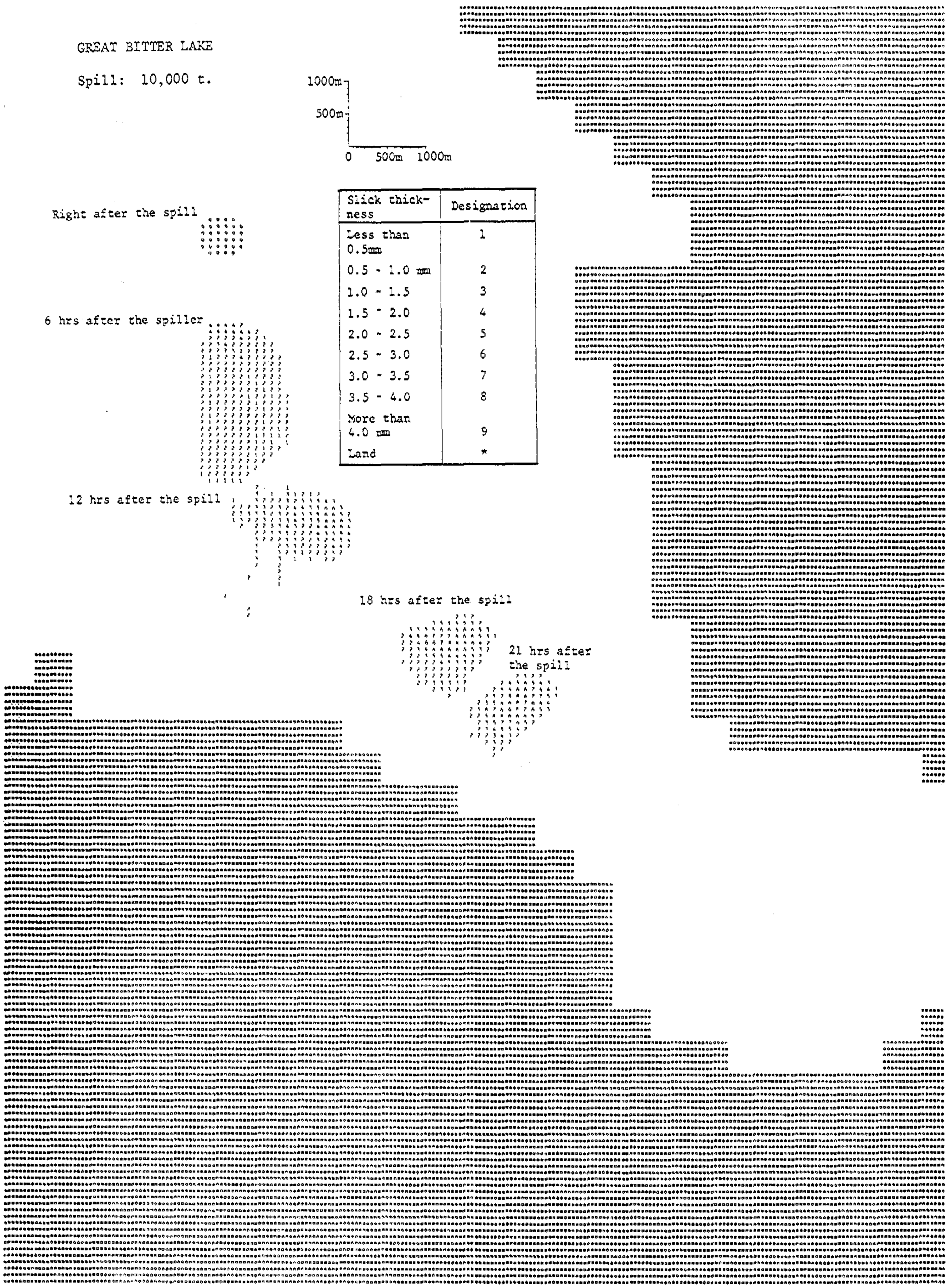


Fig. V-2-(2)-23 The Spreading of 10,000 tons of Crude Oil in Great Bitter Lake



Slick thickness	Designation
Less than 0.5mm	1
0.5 - 1.0 mm	2
1.0 - 1.5	3
1.5 - 2.0	4
2.0 - 2.5	5
2.5 - 3.0	6
3.0 - 3.5	7
3.5 - 4.0	8
More than 4.0 mm	9
Land	*

Fig. V-2-(2)-24 An Enlarged Display of the Spreading of 10,000 tons of Crude Oil in Great Bitter Lake

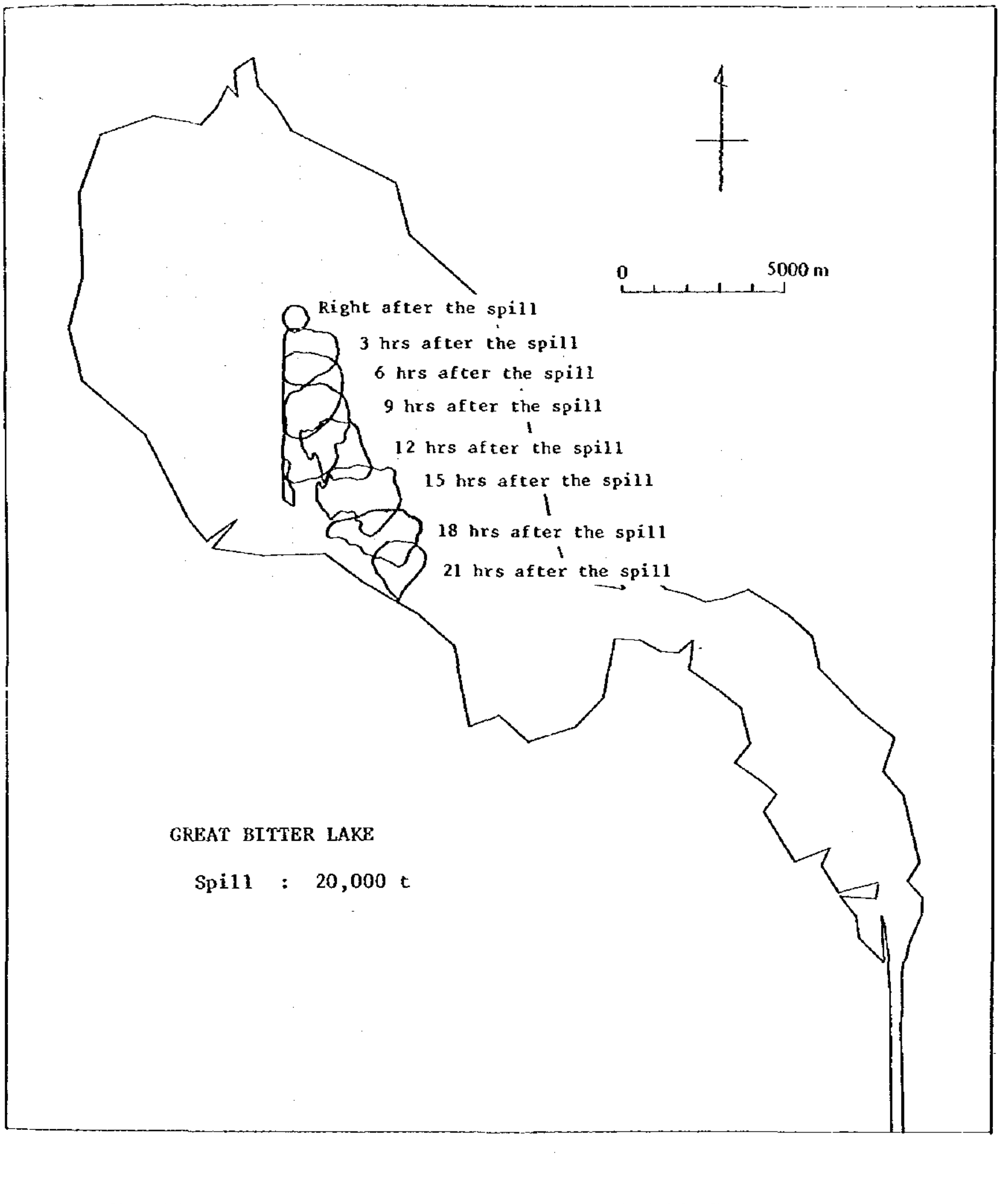
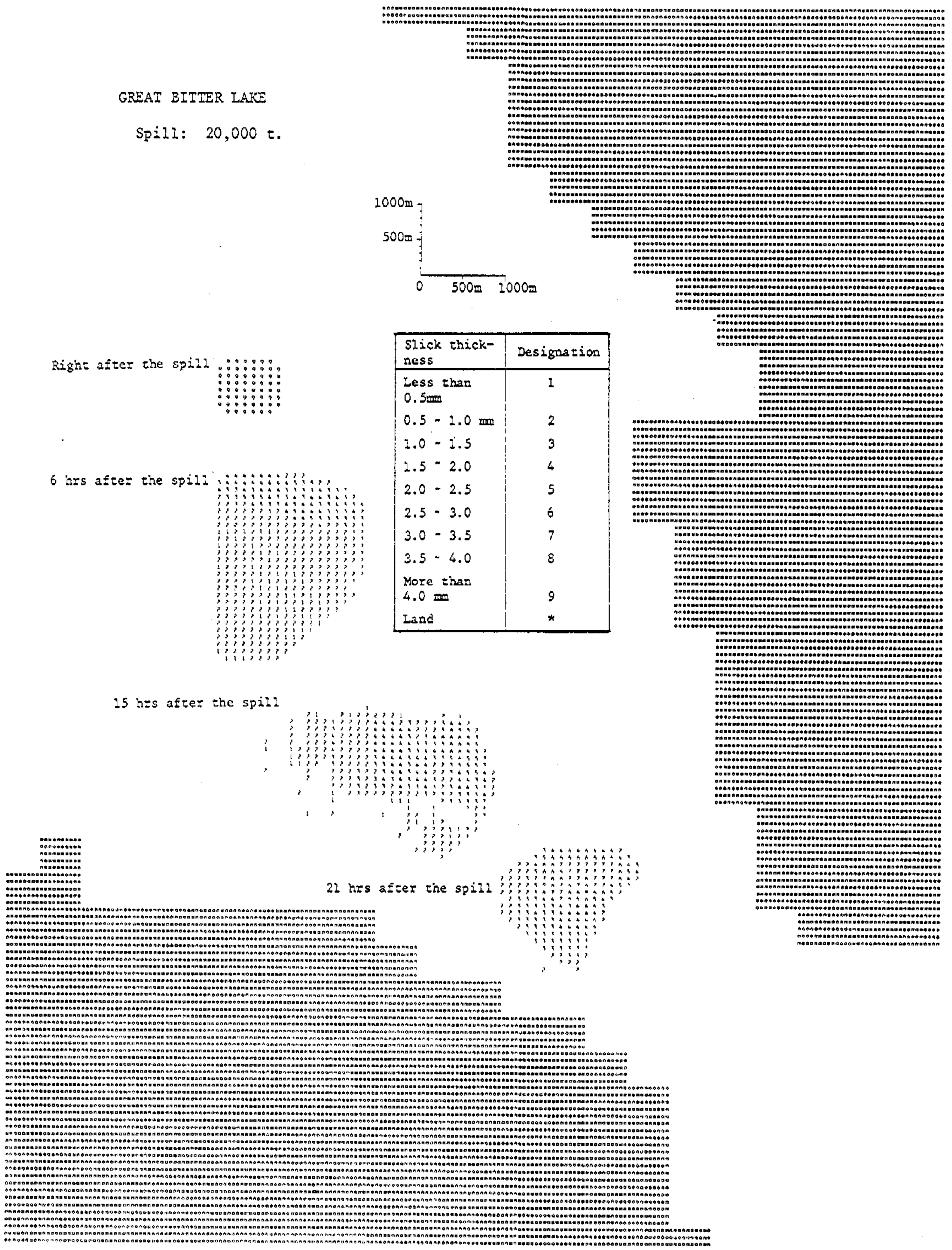


Fig. V-2-(2)-25 The Spreading of 20,000 tons of Crude Oil in Great Bitter Lake



Slick thickness	Designation
Less than 0.5mm	1
0.5 - 1.0 mm	2
1.0 - 1.5	3
1.5 - 2.0	4
2.0 - 2.5	5
2.5 - 3.0	6
3.0 - 3.5	7
3.5 - 4.0	8
More than 4.0 mm	9
Land	*

Fig. V-2-(2)-26 An Enlarged Display of the Spreading of 20,000 tons of Crude Oil in Great Bitter Lake

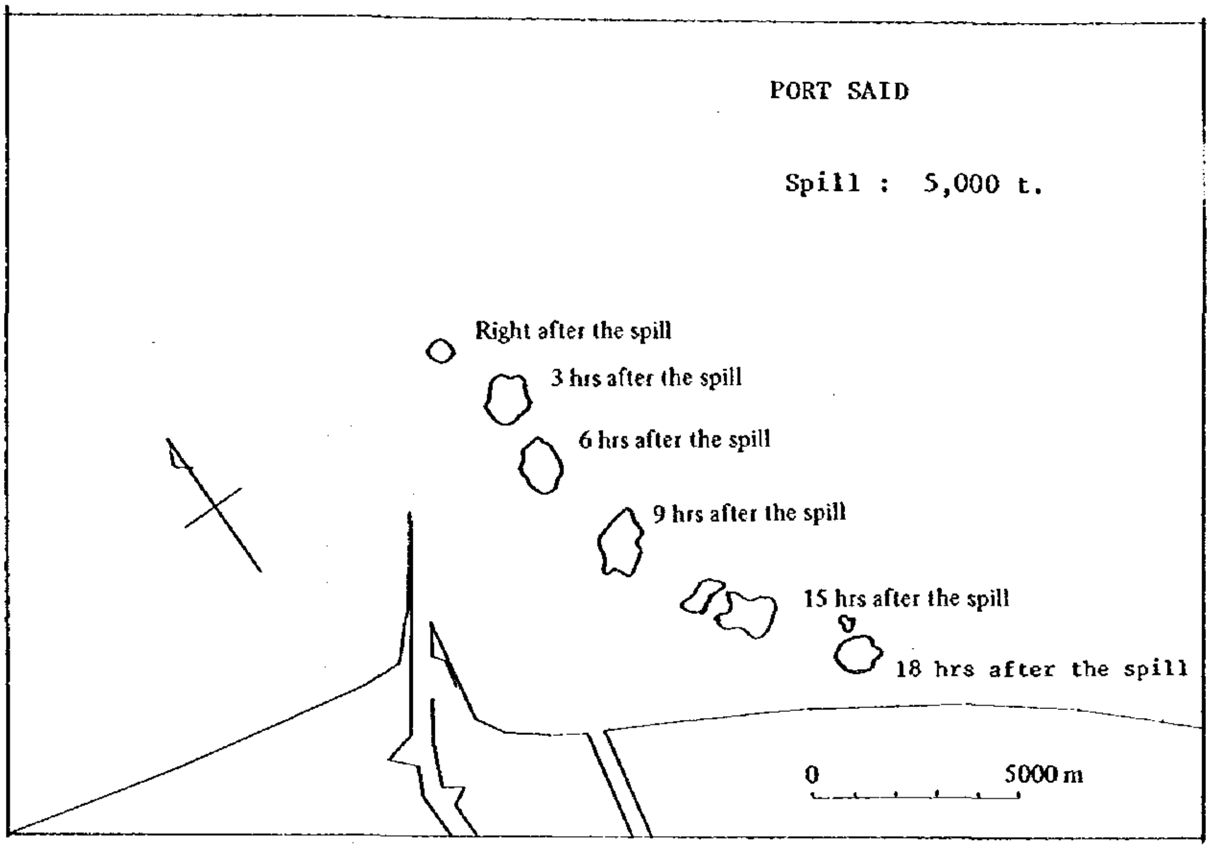
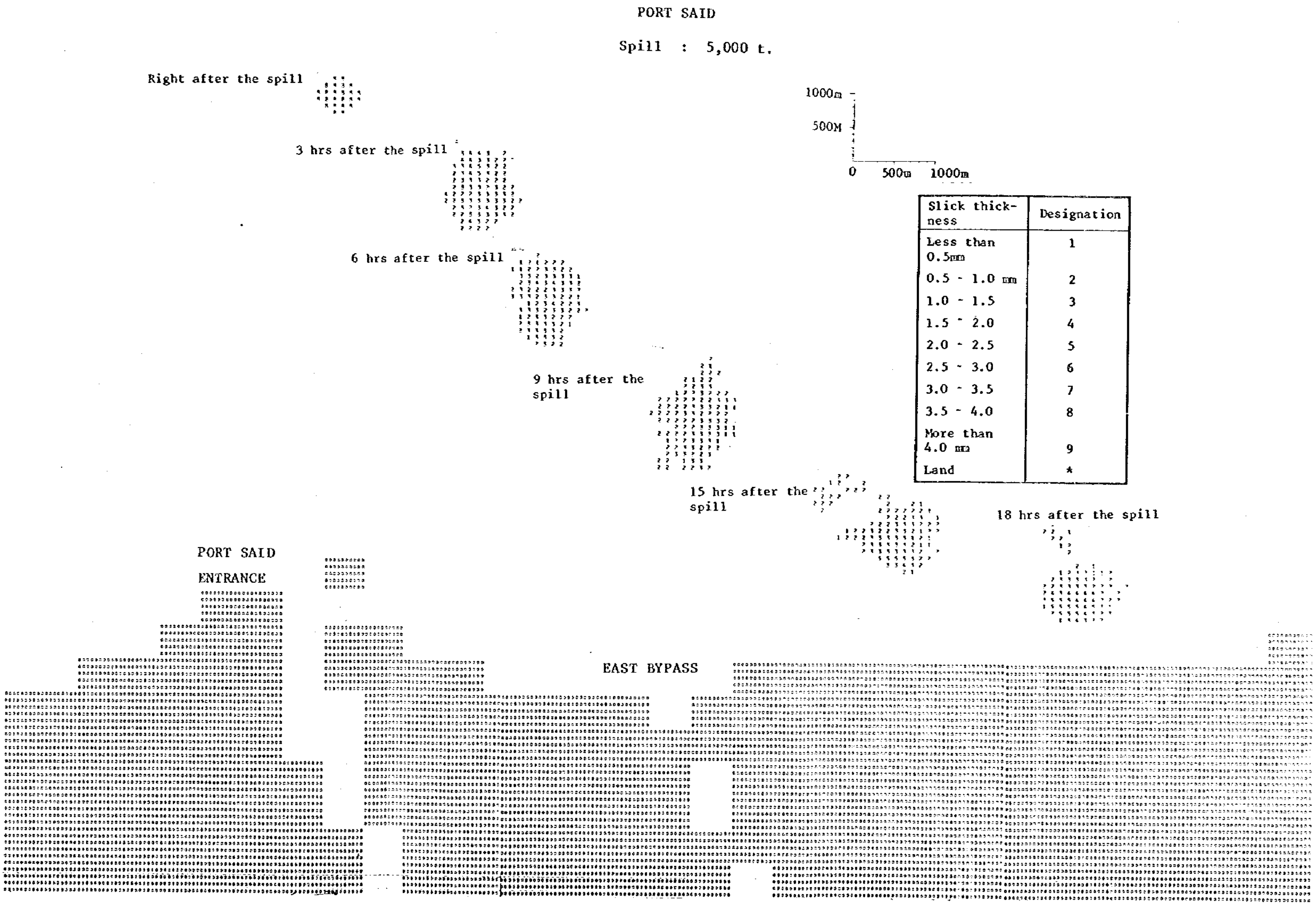


Fig. V-2-(2)-27 The Spreading of 5,000 tons of Crude Oil at Port Said



Slick thickness	Designation
Less than 0.5mm	1
0.5 - 1.0 mm	2
1.0 - 1.5	3
1.5 - 2.0	4
2.0 - 2.5	5
2.5 - 3.0	6
3.0 - 3.5	7
3.5 - 4.0	8
More than 4.0 mm	9
Land	*

Fig. V-2-(2)-28 An Enlarged Display of the Spreading of 5,000 tons of Crude Oil at Port Said

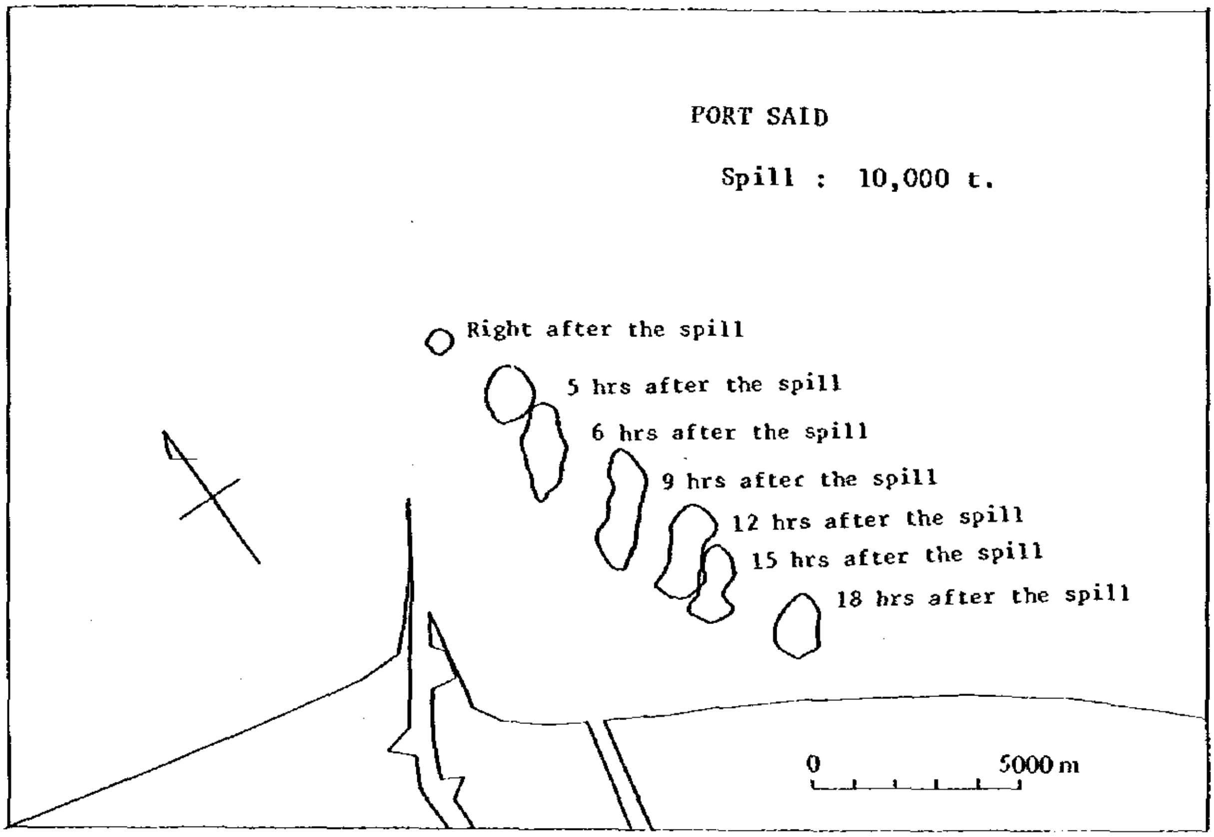
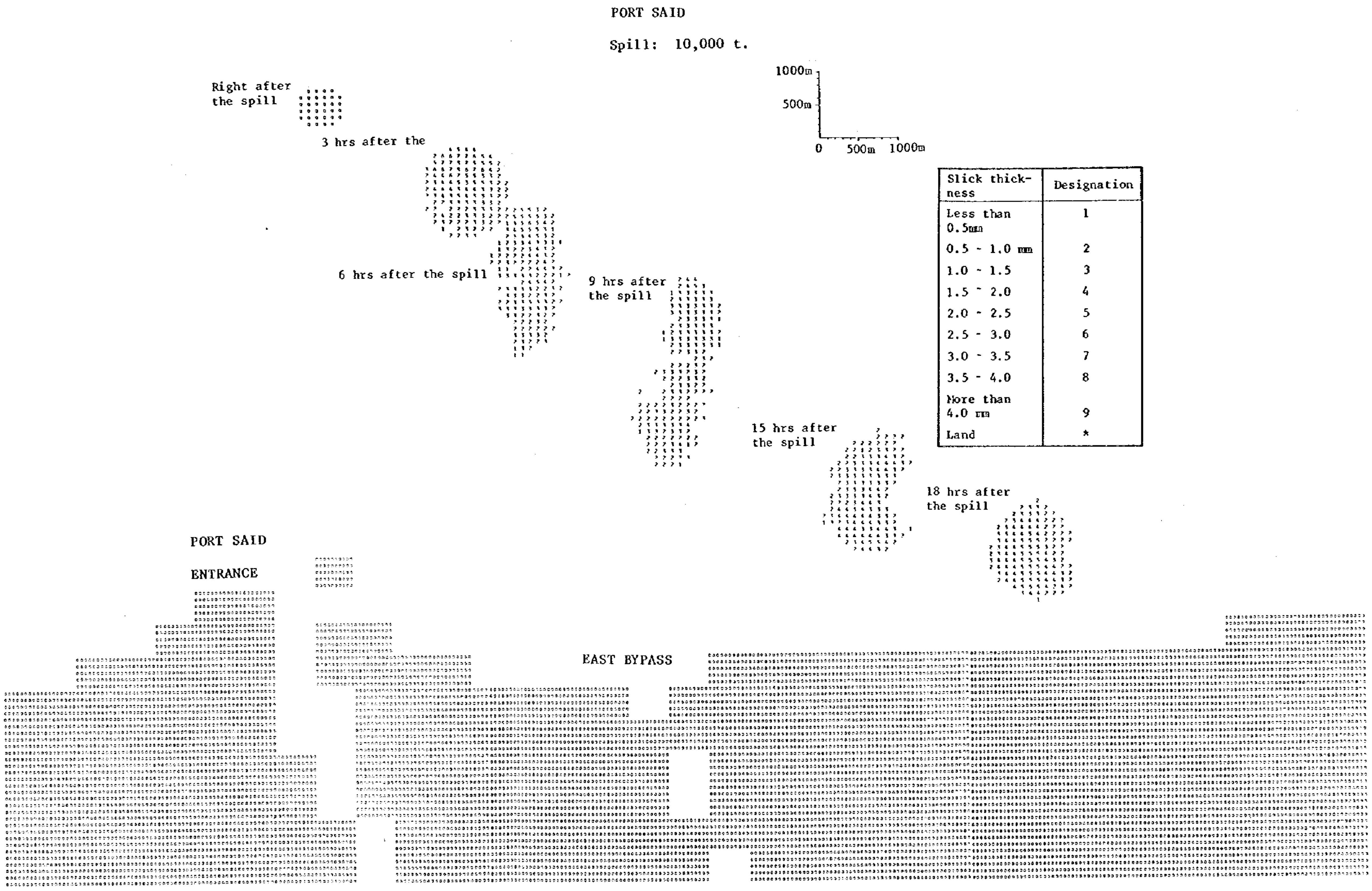


Fig. V-2-(2)-29 The Spreading of 10,000 tons of Crude Oil at Port Said



Slick thickness	Designation
Less than 0.5mm	1
0.5 - 1.0 mm	2
1.0 - 1.5	3
1.5 - 2.0	4
2.0 - 2.5	5
2.5 - 3.0	6
3.0 - 3.5	7
3.5 - 4.0	8
More than 4.0 mm	9
Land	*

Fig. V-2-(2)-30 An Enlarged Display of the Spreading of 10,000 tons of Crude Oil at Port Said

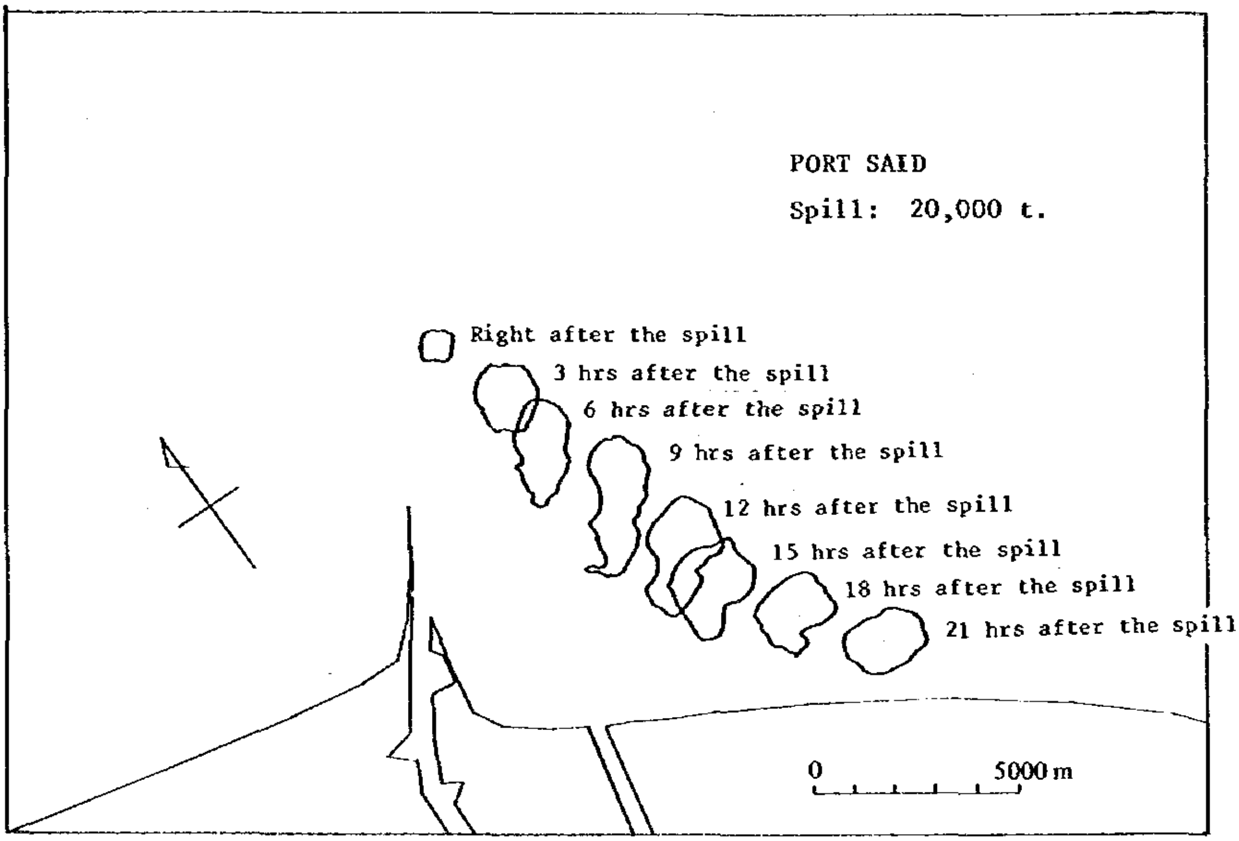
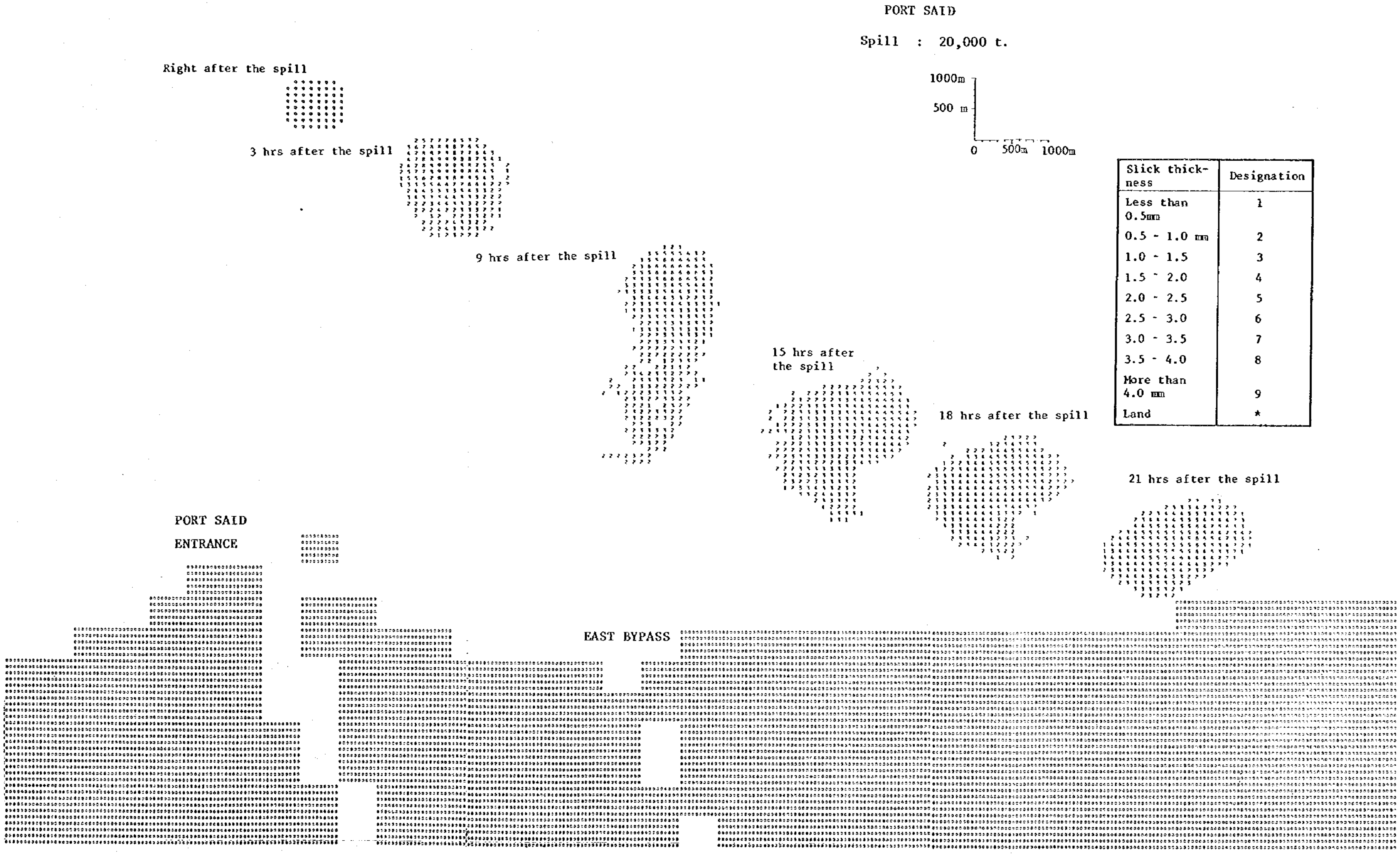


Fig. V-2-(2)-31 The Spreading of 20,000 tons of Crude Oil at Port Said



Slick thickness	Designation
Less than 0.5mm	1
0.5 - 1.0 mm	2
1.0 - 1.5	3
1.5 - 2.0	4
2.0 - 2.5	5
2.5 - 3.0	6
3.0 - 3.5	7
3.5 - 4.0	8
More than 4.0 mm	9
Land	*

Fig. V-2-(2)-32 An Enlarged Display of the Spreading of 20,000 tons of Crude Oil at Port Said

(i) Models Used

The spreading of crude oil, taking into consideration the effect of the wind and tide over each sea-area, is obtained by a calculation based on a composite assessment of the flow of the tidal current and the wind drift current in the respective sea-area, together with the spread of the spilled oil itself.

i) Tidal Current Model

(Equation concerning the motion)

$$\frac{\partial u}{\partial t} = -g\frac{\partial \zeta}{\partial x} - u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} + A_h\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - \frac{\gamma_b^2 u\sqrt{u^2+v^2}}{(\zeta+h)} + fv$$

$$\frac{\partial v}{\partial t} = -g\frac{\partial \zeta}{\partial y} - u\frac{\partial v}{\partial x} - v\frac{\partial v}{\partial y} + A_h\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) - \frac{\gamma_b^2 v\sqrt{u^2+v^2}}{(\zeta+h)} - fu$$

(Equation concerning the continuity)

$$\frac{\partial \zeta}{\partial t} = \frac{\partial}{\partial t}\left[(\zeta+h)\cdot u\right] - \frac{\partial}{\partial y}\left[(\zeta+h)\cdot V\right]$$

ii) Wind Drift Current Model

(Equation concerning the motion)

$$\frac{\partial u}{\partial t} = -g\frac{\partial \zeta}{\partial x} - u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} + A_h\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - \frac{\gamma_b^2 u\sqrt{u^2+V^2}}{(\zeta+h)} + fv + \frac{\tau_s^{(x)}}{\rho_w(\zeta+h)}$$

$$\frac{\partial v}{\partial t} = -g\frac{\partial \zeta}{\partial y} - u\frac{\partial v}{\partial x} - v\frac{\partial v}{\partial y} + A_h\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) - \frac{\gamma_b^2 v\sqrt{u^2+v^2}}{(\zeta+h)} - fu + \frac{\tau_s^{(y)}}{\rho_w(\zeta+h)}$$

(Equation concerning the continuity)

$$\frac{\partial \zeta}{\partial t} = -\frac{\partial}{\partial x}\left[(\zeta+h)\cdot u\right] - \frac{\partial}{\partial y}\left[(\zeta+h)\cdot V\right]$$

Where,

$x, y,$: Horizontal and vertical distances (m)

ζ : water level. (m)

u, v : Mean velocity of flow in the x direction, and mean velocity of flow in the y direction. (m/sec)

$\tau_s^{(x)} = \rho_a \cdot r^2 w_x\sqrt{w_x^2 + W_y^2}$: Sea surface friction in the "x" direction. ($kg/m \cdot sec^2$)

$\tau_s^{(y)} = \rho_a \cdot r^2 w_y\sqrt{w_x^2 + W_y^2}$: Sea surface friction in the "y" direction. ($kg/m \cdot sec^2$)

ρ_a, ρ_w : Densities of air and sea water. (kg/m^3)

Wx, Wy : Mean wind velocity in the "x" and the "y" direction. (m/sec)

A_h : Coefficient of vertical vortex kinematic viscosity. (m^2/sec)

r, r_b : Friction constant of the sea surface and the sea-bed.

t : Time (sec)

h : Depth of water (m)
g : Gravity acceleration (m/sec^2)
$f = 2\omega \sin \phi$: Colioris constant (sec^{-1})
ϕ : Latitude (degree)
ω : Angular velocity of the rotating earth (rad/sec)

iii) Crude Oil Spreading Model

Motora's model,

$R = (\alpha \cdot t)^{1/8}$

t : Elapsed time (sec)

$$\alpha = \frac{16 \cdot g \cdot v^3}{\pi^3 \cdot c^2 \cdot \upsilon}$$

g : Gravity acceleration (cm/sec^2)
V : Volume of oil on the water surface (cm^3)
C : Velocity gradient coefficient of oil (–)
υ : Coefficient of kinematic viscosity of oil (cm^2/sec)

Where, the vaporization of crude oil is calculated using the following formula.

$qm = : 2.12 \times 10^{-7} \times 22.9 \times (1 + 0.121 \times u^{0.85})$

qm : Rate of vaporization (gr/s/cm^2)
U : Gas transfer velocity (cm/sec)

(ii) Calculation Factors

i) The Spill

5,000, 10,000, and 20,000 tons

ii) The Site of Spill

Port Said: 31°19'6N and 32°22'3E
Great Bitter Lake: 30°21'1N and 32°22'5E.
Suez Bay: 29°48'6N and 32°33'2E.

iii) Kinematic Viscosity of the Oil 0.1

iv) Average Velocity Gradient Coefficient of the Oil 0.1

v) The Drift Condition

The calculated composite current of the tidal and wind blow was adopted as the drift condition. The conditions of the tide and wind for this calculation are given in Table V-2-(2)-10.

Table V-2-(2)-10 Conditions of Tide and Wind for Calculation of Composite Current

Water area	Current Conditions	
Port Said	Tide	Data of tidal level of Port Said and EL-Tina
	Wind	Wind direction: NNW, wind speed: 8 m/sec.
Great Bitter Lake	Tide	Data of tidal level of Diversoir and Shallufa
	Wind	Wind direction: N, wind speed: 8 m/sec.
Suez Bay	Tide	Data of tidal level of Shallufa and Port Taufig.
	Wind	Wind direction: N, wind speed: 8 m/sec.

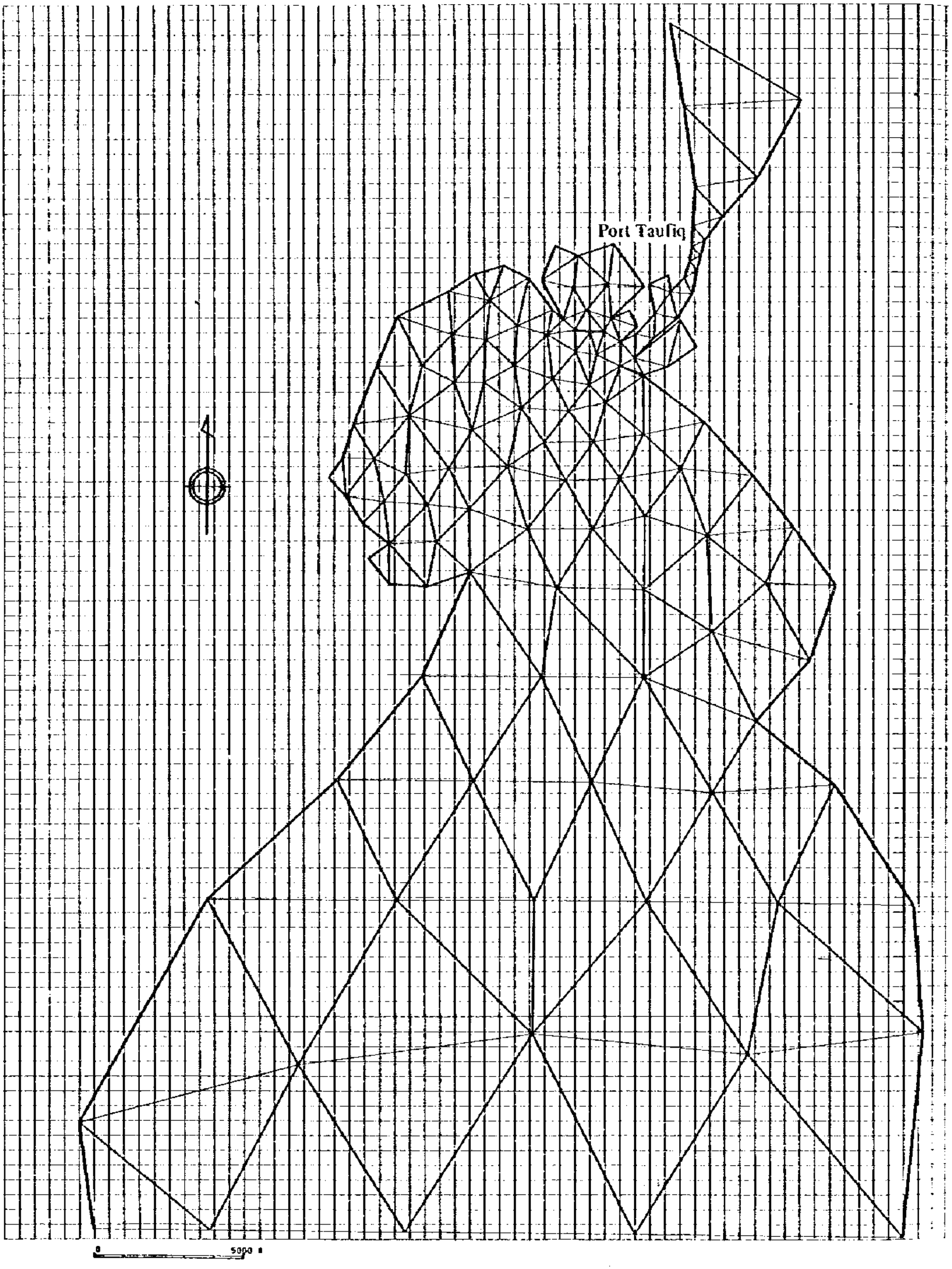


Fig. V-2-(2)-33 Element Division (Suez Bay)

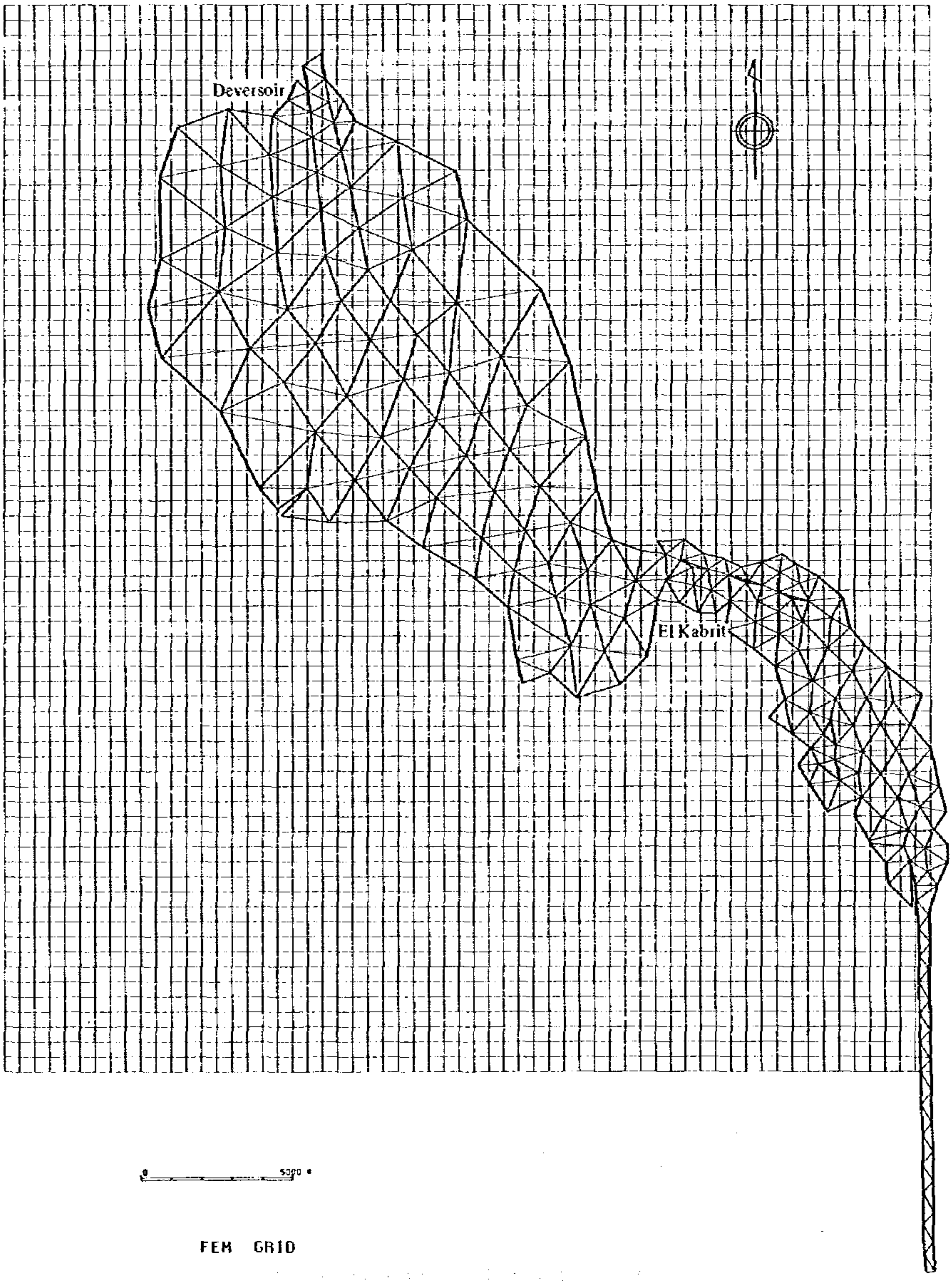


Fig. V-2-(2)-34 Element Division (Great Bitter Lake)

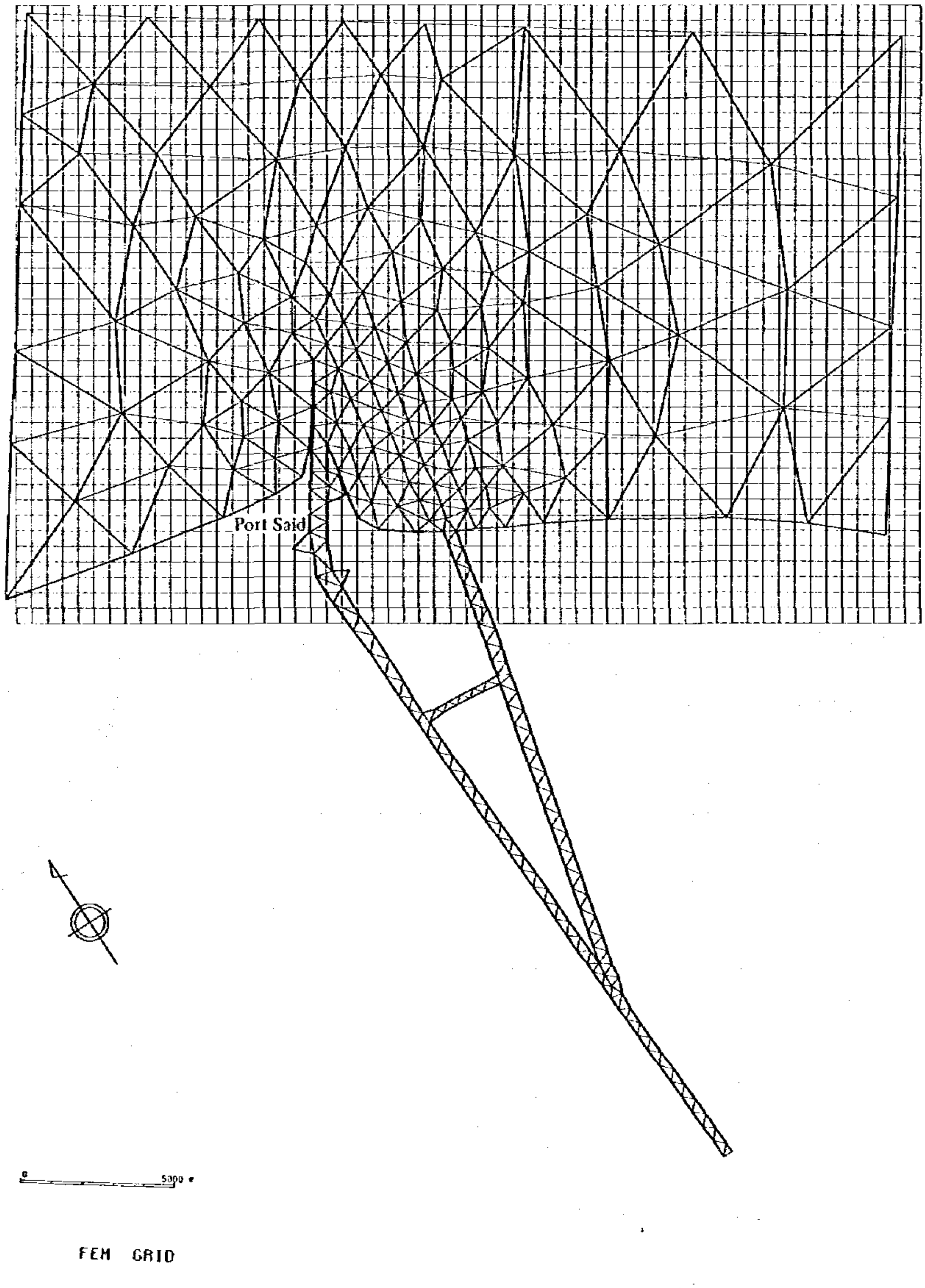


Fig. V-2-(2)-35 Element Division (Port Said)

5) Influences of Spilled Cargo

(i) Influences on Navigation

The cargo spilled on the sea generates inflammable gases. Therefore, transit vessels in the vicinity can not continue to navigate until gases disappear completely. However, the residual oil after the gases have evaporated is relatively safe, and vessels may pass unless one worries about staining of the outside of the hull and the contamination of cooling water with oil, etc. However, they should navigate at the lowest speed when pass through the very close area to the oil booms, because the wave generated by high speed may cause escape of oil from the boom containment.

(ii) Influences on the Marine Fauna and Flora

Spilled oil is known to exert a throughly destructive influence upon the living conditions of organisms. Spills hamper the exchange of oxygen and other gases between the atmosphere and the water, impede light transmission into the water, and promote the increase of water temperature. Spills also make organisms stink, hinder their biological processes, like growth and reproduction, and further annihilate organisms by directly exerting harmful physical and chemical effects on them.

As for the sea weeds, their biological functions are said not to be seriously harmed when oil pollution is slight, because their exterior surface is usually covered with mucilage which makes oil difficult to adhere to them. However, sea weeds living near the high tide line and exposed to the air when the tide is low are known to show a malfunctioning of the photosynthesis process, resulting in the fading of pigments.

As for shellfish, those having bissi are known to become liable to come off rocks. It is also known that the dissolved components of petroleum may destroy their ability to take in nourishment and force them to die.

As for fish, it is said that although their body surfaces are protected by mucous membrane, as sea weeds are, once oil sticks to the gills, their cells are destroyed by the hazardous components of oil and their ability to exchange gases is impeded, forcing them to die. Fishery products from oil-polluted sea areas are known to carry a bad smell. Common fishes living in water polluted with oil at a concentration of 0.01 ppm, and submarine fishes living longer than a day on a sea-bottom polluted with oil at a concentration of 0.2%, are said to stink, too*.

*(Oil pollution and marine organisms: The Japanese Society of Scientific Fisheries)

In oil-polluted sea areas, the suppression of growth and even death are observed not only of aquatic flora and fauna, but also of floating organisms that are consumed by fish and shell fish. In sea areas where a large oil spill has occurred, the ecological balance of flora and fauna will be lost for a considerable period of time, thus retarding their growth and, in turn, decreasing the catch of fish.

6) The Possibility of Fire after the Spill of Crude Oil and Liquefied Gas

When Crude oil or liquefied gas is spilled on the sea, inflammable gases are generated from the spill. If there is an ignition source within the range of inflammability, a fire will occur easily. When vessels collide, there is always possibility of fire, because a frictional heat is generated with the breaking of the holds.

Typical ignition sources after spill in the case of Suez Canal are identified as follows:

(i) Static Electricity

Static electricity accumulated on peoples' bodies and clothes generate energy which sometimes exceeds the minimum ignition energy and thus may become an ignition source. For instance, the electrostatic capacity of a man wearing shoes with a sole 10 mm thick is estimated at 200 $\mu\mu$F and if the static electricity is discharged after he has been charged up to a voltage 3,000 V, the discharge energy will amount to 0.7 mJ, which can easily ignite methane, propane, or crude oil gas. It is no exaggeration to say that electrostatic energy of this amount is generated at any time anywhere. Incidentally, the minimum ignition energy requirements of methane, propane and butane, and petroleum gas are 0.5, 0.3, and 0.2 mJ, respectively.

(ii) Electric Sparks

Examples are sparks generated at switches of smaller electric appliances, those due to short circuits, making and breaking of circuits, breaking of electric wiring, leakages of electricity, and breakage of electric bulbs, and also those occurring in electric motors, electric weld, gasoline engines, miniature tranceivers, wireless microphones, automobiles on the Canal road, etc.

(iii) Induction Sparks due to Radiocommunications

(iv) Strike of a Thunderbolt

(v) Sparks due to Friction and Impact between Metals.

Sparks due to impact or friction between iron and iron, or iron and stone, etc., are examples. There are also those due to impact between light metals, and due to the thermite reaction.

(vi) High Temperature Surfaces

For example, an electric heater and an exposed part of exhaust pipe of an internal combustion engine of vessel.

(vii) Sparks Ejected from an Exhaust Pipe of an Internal Combustion Engine, or those from a Chimney of Stove, etc.

(viii) Bonfires and Oxyacetylene Flames

(ix) Tobacco, Lighters and Matches

7) Crude Oil and Liquefied Gas Fires

(i) Crude Oil Fire

i) When Ignited right after the Spill

The lighter components of crude oil rapidly burn first, and then the heavier components gradually evaporate and burn. The heavier the specific gravity of the component, the slower its burning speed. The fire comes to an end leaving very heavy components unburned.

The burning speed is rather fast, approximately 6 mm/min for lighter components, and 1 mm/min for heavier ones. When 10,000 m^3 of spilled crude oil has spread over an area of 500,000 m^2, the average thickness is about 20 mm, and it is expected that the peripheral parts will be burned within 20 or 30 min., with the area of the fire narrowing rather rapidly.

Therefore, the fire becomes limited to a relatively narrow area around the burning tanker within approximately 20 ~ 30 min after the ignition, and the broken tanker continues to burn for a long time until the remaining oil is exhausted.

On the other hand, it is possible that another tank may be exploded by the peripheral fire to cause an additional oil spill from the crack, resulting in the propagation of the sea fire. However, the possibility of simultaneous explosions of more than one tank is quite small, and also the side breakage due to an explosion is presumed to be relatively small. Therefore, it may be reasonable to assume that the area of sea fire spreading with each tank explosion will not exceed that of the initial fire.

It is also possible that the burning oil will drift due to tidal current and the wind. The drift distance, however, seems to be not very far, because the burning speed is fairly fast.

In conclusion, when ignited right after the spill, the hazardous area may be relatively small and the oil spill may continue to burn for a long time. The problem of oil pollution may be relatively unimportant since spilled oil will burn out, leaving only the very heavy components.

ii) When Ignited after some interval following the Spill

In this case, the spilled oil will spread over the sea sufficiently, and inflammable gases generated by the evaporation of volatile components will cover a considerable area of sea surface, sometimes spreading further than the range of the oil spread.

When the inflammable gases thus generated are ignited, a fire not only covers the vicinity of the place of ignitions but also all the oil area covered by diffused gases, eventually resulting in a wide sea fire. Although the rate of progress thereafter is almost the same as when a fire is ignited right after the spill, the hazardous range may become larger, because of the longer time lapse until the ignition allows the oil to spread much farther from the troubled vessel, due to the spread and the influence of tidal currents, etc.

(ii) Liquefied Gas Fire

i) When Ignited right after the Spill (Pool Fire)

Liquefied gas spilled on the sea spreads fire. Its spreading range, however, will not be large because the liquid will be consumed rapidly due both to the fast-burning speed of the gas and the promotion of the evaporation by the heat of the fire. Nevertheless, the scale of fire is larger and the heating power is stronger than these of the crude oil fire. The termination of the liquid spill ends the sea fire as the spilled liquid burns out in a relatively short period of time.

After the fire, gases generated from the remaining liquefied gas in the vessel come out to mix with the open air, and burn as the mixtures reach the range of flammability. The flame is steady and does not change its location and length unless conditions, such as the rate of release of vaporized gases, vary.

ii) When Ignited after Some Interval following the Spill (Vapor Cloud Fire)

When ignited after the inflammables gases generated from the liquefied gas spilled on the sea get well-mixed with the air, the produced flame propagates in the mixed gas. When the release of gas is very large, in its amount and rate, a violent explosion called detonation may sometimes occur as the propagation of flame is accelerated. The so called BELVE (Boiling Liquid Expanding Vapor Explosion) phenomenon may occur if other tank are exposed to the strong heat of the fire, irrespective of the time of ignition after the spill.

8) Scale of Pollution and Fire

(i) Crude Oil Tankers

i) Maximum Spill

In general, there will be two types of accidents in which a loaded crude oil tanker may cause break in its cargo tank and let the oil spill. One is grounding and the other is collision with another vessel.

Groundings are considered to give a vessel only relatively minor damage because the bottom of the Suez Canal is sand. Also the oil spill is expected to be relatively limited since the break will be made in ship's bottom, and the spill will be due only to the head difference.

On the other hand, collisions have probability that may cause such breaks that all the oil in the tank is likely to be spilt.

Therefore, spills due to collisions, rather than groundings, are considered herein.

The number of tanks broken by a collision depends on the type, the size, and the speed of colliding vessels, and also on the part affected by the collision. A collision, if it ever occurs, may cause damage to only the side tanks but not the central ones, because in the Suez Canal vessels are boards by a pilot and carefully operated at low speeds. Therefore, the maximum number of tanks that spill oil from the break on the side of a vessel can be estimated as two.

The maximum oil spill against dead weight tonnage estimated on the basis of the conditions mentioned above, and according to the codes set by the International Marine Organization, is shown in Fig. V-2-(2)-36.

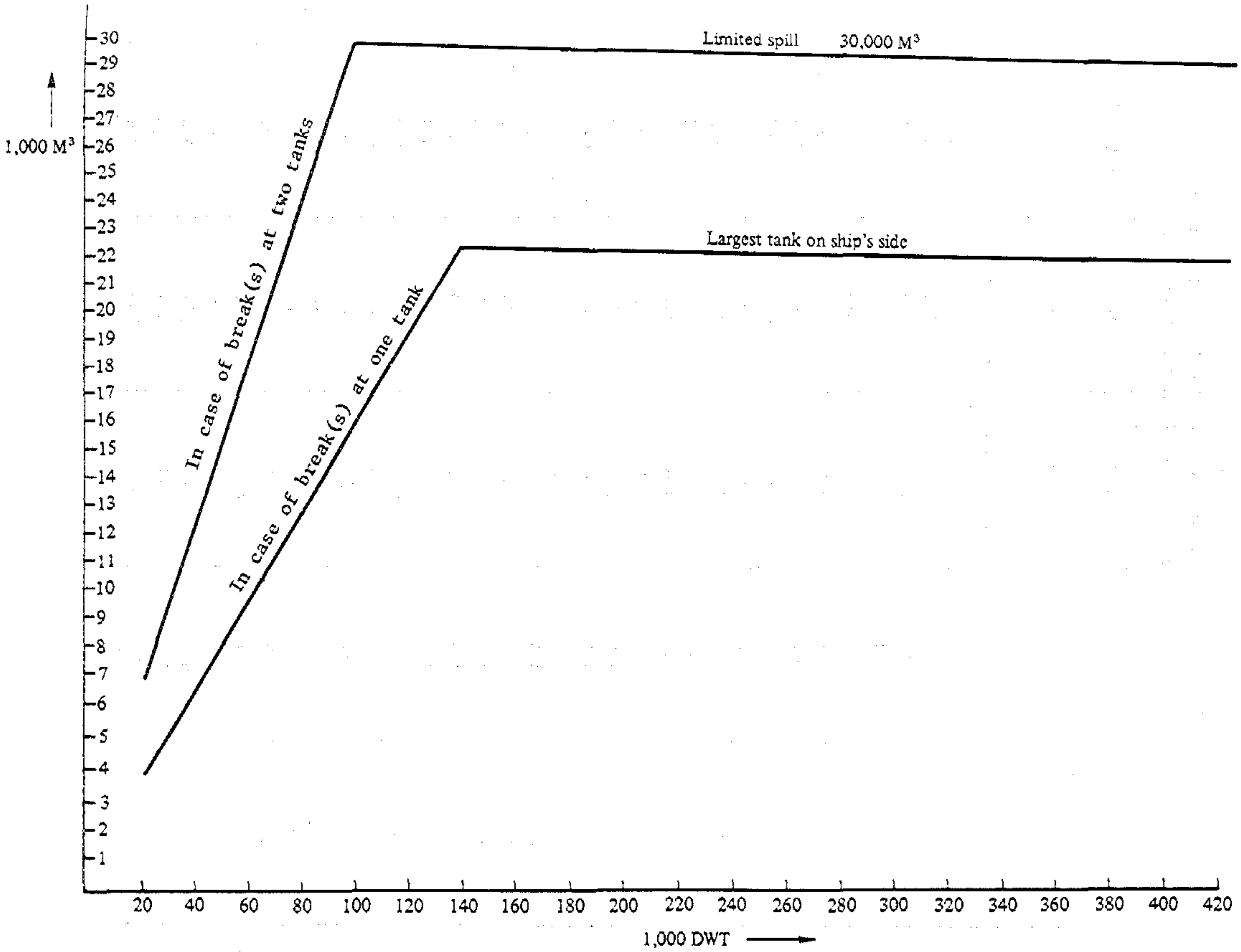


Fig. V-2-(2)-36 Estimated Maximum Oil Spill against Dead Weight Tonnage of Vessels

The time involved to complete evaporation, and the radii of the spread for different crude oil spills are shown in Table V-2-(2)-11.

Table V-2-(2)-11 The Time Involved to Complete Evaporation, and the Radii of the Spread for the Different Oil Spills

Crude Oil Spill	5,000 t.	10,000 t.	20,000 t.	30,000 M^3
Time Involved to Complete Evaporation	74 min.	85 min.	97 min.	103 min.
Time Elapsed (h)	Radii of the Spread of Crude oil Spill (m)			
1	332	431	558	614
2	355	462	600	661
3	373	484	627	690
4	387	501	650	715
5	398	516	669	736
6	407	527	684	753
7	415	538	697	767
8	422	547	709	780
9	428	555	720	792
10	434	562	729	802
11	439	569	738	812
12	444	575	746	821
13	448	581	753	829
14	452	586	760	837
15	456	591	767	844
16	460	596	773	851
17	463	601	779	857
18	467	605	785	863
19	470	609	790	869
20	473	613	795	875
21	476	617	800	880
22	478	620	805	885
23	481	624	809	890
24	484	627	813	895
25	486	630	818	899
26	489	634	822	904
27	491	637	825	908
28	493	639	829	912
29	495	642	833	916
30	497	645	836	920
31	499	648	840	924

ii) The Magnitude of Fire

It is well-known that a just spilled quantity of crude oil may sometimes catch fire simultaneously with the collision due to ignition caused by heat or fire resulting from friction between stell sheets. The resulting fire can cover not only the spreading spilled oil, but also the remaining oil in the broken tank exposed to the atmosphere. The former dies out in a relatively short period of time, but the later usually burns for a long time, depending on the amount of oil in the open tank.

The fire area of the latter when two tanks are broken is the surface area of the 2 tanks, and its maximum area may be given approximately by dividing maximum tank volume by average depth of the vessel. Maximum fire area is estimated as follows.

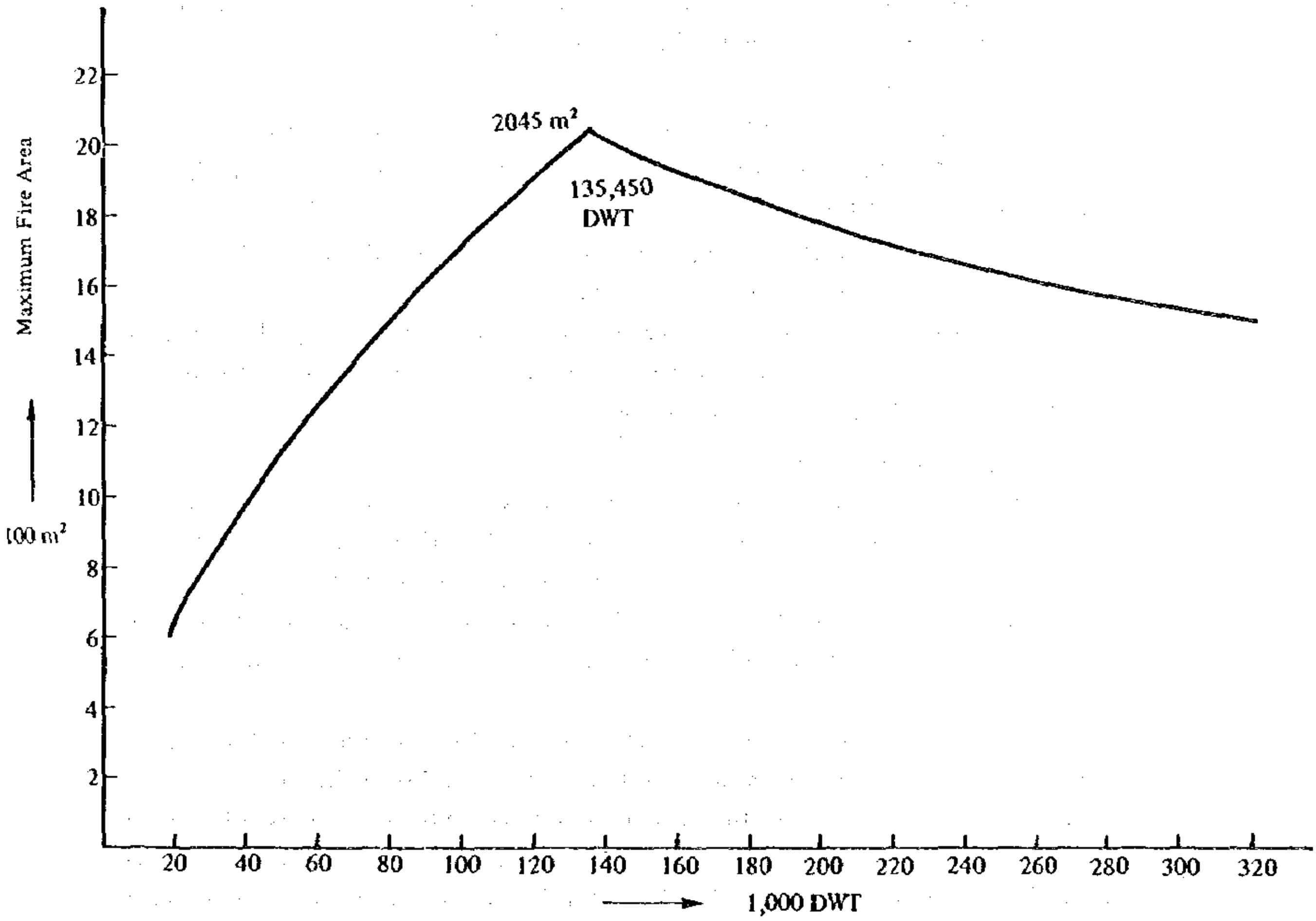


Fig. V-2-(2)-37 Maximum Fire Area of 2 Tanks

(ii) Liquefied Gas Tanker

According to United States Coast Guard statistics, damage affecting cargo tank can be avoided with a probability of more than 90% in the event of grounding because liquefied gas tankers have a strong double hull structure on the sides and the bottom of the tanker.

Moreover, the bottom deposit in the Suez Canal is generally sand. It is, therefore, almost untihnkable that the grounding of a tanker in the Suez Canal would result in a severe accident involving a large amount of spill of liquefied gas on the sea.

On the other hand, a collision between either a LNG or LPG tanker and another vessel may cause damages to liquefied gas tanks and set the spill on fire, if the sizes and speeds of vessels happen to aggravate the conditions of the accident.

For the purpose of accident estimation, a hypothetical collision of a LNG tanker is studied, since such a collision gives damages much worse than a grounding does, and since a LNG tanker carries larger intrinsic risks, (such as "brittle fracture"), than a LPG tanker although the collision scenario may be the same for both.

i) Tanker Studied

The largest loaded LNG tanker that has ever transited the Suez Canal is POLLENGER with a gross capacity of 88,052 m^3, and the largest LPG tanker that has transited is Al BERRY with a gross capacity of 77,170 m^3.

However, the world demand for LNG is increasing and main LNG tanker in the world is capacity of 125,000 M^3 type tanker.

Therefore, there is a probability that loaded 125,000 M^3 type LNG tankers will travel through the Suez Canal in the future. That is why a 125,000 m^3 LNG tanker is chosen as the subject of the accident study.

ii) Magnitude of Accident

Because the sides of liquefied gas tankers are reinforced by the double hull structure, it is implausible that a mild collision like those which may occur even in such a safe waterway as the Suez Canal (boarded by a pilot, low speeds, one-way traffic, convoy system) should cause damages resulting in the spilling of the liquid. Even if damages to a cargo hold may occur, they are expected to be quite a small break or a crack.

Two undesirable consequences are expected to arise from a spill of liquid from such small breaks or cracks. One is "brittle fracture" and the other fire.

As regards "brittle fracture", if the liquid whose temperature is as low as −162°C spills on ordinary steel sheets, such as those of the hull and the deck, the affected part of the hull is rapidly "quenched" to very low temperatures, enough to generate a thermal stress not only locally but also on the entire hull structure. Thus, cracks may appear in the hull by the brittle fracture with other additional stress, because steel sheets are "quenched" to a cryogenic temperature and further subjected to stresses.

As for fire, analogous to the case involving crude oil, inflammable gases generated by evaporation may be ignited by the frictional heat of collision or by other ignition sources.

According to a study made by the Japan Association for Preventing Marine

Accident (JAPMA), a spill rate of 5.28 m³/min. from a break made at the draft line of a spherical tank vessel with gross capacity of 125,000 m³ will make a sea fire over an area of 145 m², and a spill rate of 21.11 m³/min from same ship will make a fire over an area of 580 m².

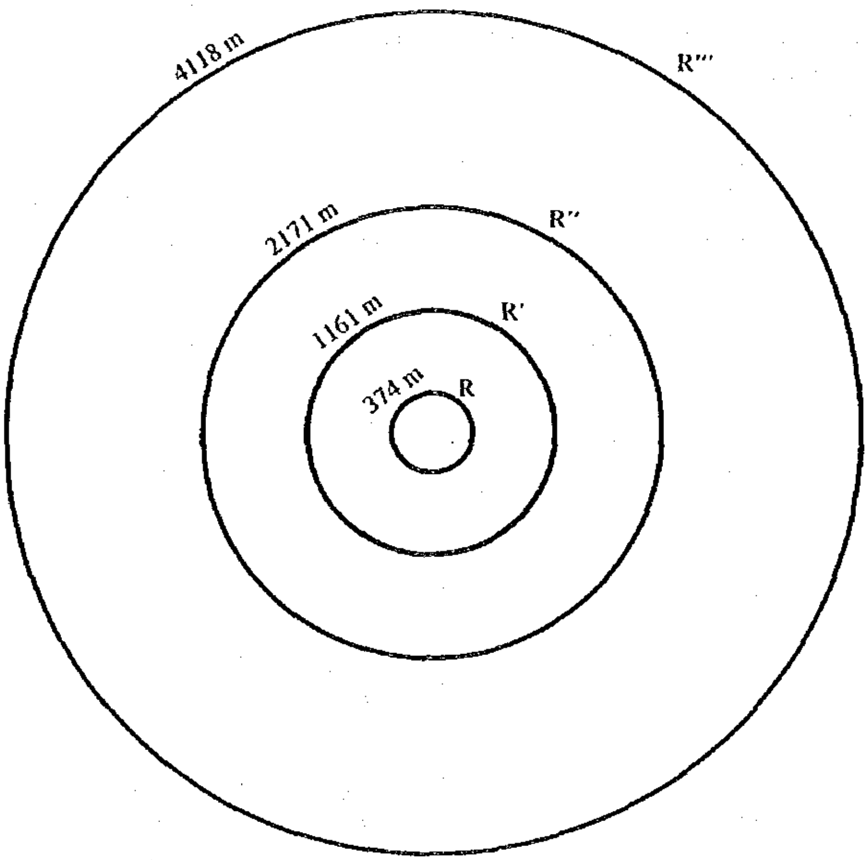
For the purpose of easy reference, an almost improbable accident supposed by JAPMA in which a break of 5 or 10 m² is made on a cargo tank with a capacity of 25,000 m³ on a 125,000 m³ type tanker is described as follows.

Table V-2-(2)-12 The Scale of Supposed Fires

Type of Tank	Break Area (m²)	Break Position above Draft Line (m)	Average Spill Rate (m³/min.)	Fire Diameter (m)	Duration of Combustion* (min.)
Spherical	5	0	3,360	340	6.81
	5	5	2,830	315	6.53
	10	0	6,720	485	3.40
	10	5	5,660	445	3.26
	15	0	10,080	595	2.27
	15	5	8,490	545	2.18
Membrane	5	0	2,530	300	7.02
	5	5	2,040	265	5.68
	10	0	5,060	420	3.51
	10	5	4,080	380	2.84
	15	0	7,590	515	2.34
	15	5	6,120	465	1.90

* With the termination of LNG spill, the scale of fire diminishes rapidly and the fire dies out in quite a short time.

The calculated results of fire diameter and the radiant heat when 25,000 m³ of LNG is spilled at a time and ignited, are as follows:



R : Fire radius
R′ : Pain after 3 sec, blisters after 10 or 20 sec.
R″ : Pain after 10 or 20 sec.
R‴ : Distance of maximum radiant heat involving a long period of exposure which one can endure.

Fig. V-2-(2)-38 Maximum Spreading Impact of the Burning Surface of 25,000 m^3 LNG

Table V-2-(2)-13 **The Spreading Radius of the Burning Surface of 25,000 m^3 of Spilled LNG, and the Corresponding Distances from the Flame Center where the Specific Injuries are likely to a Human Body.**

Elapsed Time (sec.)	R (m)	R' (m)	R'' (m)	R''' (m)
10	302	936	1751	3321
20	312	966	1807	3427
30	321	994	1860	3527
40	329	1030	1908	3619
50	337	1044	1954	3706
60	344	1067	1996	3785
70	351	1087	2034	3858
80	357	1106	2069	3924
90	362	1122	2100	3983
100	367	1137	2127	4033
110	370	1148	2149	4075
120	373	1157	2165	4106
130	374	1161	2171	4118

The maximum spread of the radius of burning surface of 25,000 M^3 of spilled LNG is attained when the spread terminates at 130 seconds after the spill.

(3) Collation of Results

All estimated probabilities are summarized in Table V-2-(3)-1. Considering the weighted average of various sections of the Canal, the Second Stage Development Project makes the total risk level decrease by about 45% from 3.01×10^{-3} to 1.65×10^{-3}.

The number of grounding accidents is much larger than the others. Thus, reduction of grounding accidents would contribute to the improvement of the total risk level.

As for the execution period, the risk level increases due to collisions between vessels and dredgers by some 10%.

Table V-2-(3)-1 Summary of Accident Probabilities

Phase Location	Phase I (at Present)				During the Execution	Phase II (after the Expansion)			
	Grounding	Rear-end Collision	Collision	Total	Collision with Dredger	Grounding	Rear-end Collision	Collision	Total
Port Said and Suez	4.53×10^{-4}	–	4.65×10^{-4}	9.18×10^{-4}	9.74×10^{-4} 5.62×10^{-5}	2.10×10^{-4}	–	4.65×10^{-4}	6.75×10^{-4}
Ballah Bypass	1.59×10^{-5}	2.60×10^{-7}	–	1.62×10^{-5}	7.02×10^{-5} 5.40×10^{-5}	1.74×10^{-6}	1.39×10^{-8}	–	1.75×10^{-6}
Bitter Lakes	–	–	8.11×10^{-5}	8.11×10^{-5}	8.11×10^{-5} –	–	–	8.11×10^{-5}	8.11×10^{-5}
Other Parts of the Canal	1.49×10^{-3}	2.24×10^{-5}	4.82×10^{-4}	1.99×10^{-3}	3.09×10^{-3} 1.10×10^{-3}	4.13×10^{-4}	4.15×10^{-6}	4.82×10^{-4}	8.99×10^{-4}
Total	1.96×10^{-3}	2.27×10^{-5}	1.03×10^{-3}	3.01×10^{-3}	4.22×10^{-3} 1.21×10^{-3}	6.25×10^{-4}	4.16×10^{-6}	1.03×10^{-3}	1.65×10^{-3}

Note: Phase I : The First Stage Development Project
Phase II : The Second Stage Development Project