FIELD SURVEY FOR SILTATION STUDY

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I. FIELD SURVEY FOR SILTATION STUDY

Field Survey for Siltation Study

1. Introduction

The deposition of soil materials into navigation channels by siltation is caused by the process of transportation and deposition of fine cohesive sediments, which are suspended in rivers or eroded from the bottom surface through some action. Therefore, it is important to investigate the mechanism that causes the erosion, transport and deposition of fine particles and to observe the tides, waves and current conditions as external forces that determine the behavior of bottom sediment and its properties.

2. Acquisition of field survey data

The structure of siltation at a river's estuary is as follows.

As soil materials are carried downstream by rain water from mountainous areas, sand particles of a large grain size settle on the river bed quickly. However, silt or clay of a small grain diameter do not settle easily and are carried downstream. The color of rivers in Southeast Asian countries and China is yellowish due to the large amount of fine soil particles that are contained in the river water. The soil materials which are carried downstream by river water gradually settle on the river bottom as its flow velocity slows down in its lower reaches. In the rainy season, when there is a large amount of water flow discharge, the flow velocity of the river increases, and soil materials deposited on the river's bottom are eroded and transported downstream. They then flow out to the estuary or into the sea.

Due to their fine grain size, the suspended soil materials that are carried downstream in this way settle very slowly and for the most part they do not settle at all. However, when the river water comes into contact with sea water in the estuary, the suspended materials act changes slightly different. In fresh river water, fine particles of soil materials are suspended independently due to the repulsive force (Van der Waals force) that acts on them. In the sea, however, these particles form flocs as a result of the attractive force among particles caused by positively charged ions contained in sea water. Though these flocs are very soft, their total diameter increases as they stick to each other and their settling velocity increases. As a result of the above-mentioned behavior, fine suspended particles settle on the bottom in the estuarine area. Sediments thus settled on navigation channels and mooring basins in harbors are consolidated and hardened with the passage of time. Such deposited sediment can obstruct ship navigation and the function of the port. This phenomenon is called "siltation". The phenomenon of large quantities of soil materials being carried downstream and settling in estuarine areas cannot be avoided unless the supply source of the soil materials is removed. Ingenious devices that prevent soil materials from obstructing ship navigation and the functions of ports are important in fighting siltation.

When considering the problem of siltation and measures to be taken to solve it, it is very important to obtain accurate knowledge of the mechanisms that are involved in the erosion, transportation and deposition of sediment materials. In order to clarify the mechanism of siltation, it is necessary to obtain data on natural conditions, topographical conditions, soil properties and the local sedimentation. By simultaneously measuring natural conditions and the siltation volume during representative periods, it is possible to discover the mechanism of siltation in detail and to estimate the annual siltation volume by using the relevant statistics concerning natural conditions throughout the year. Furthermore, an understanding of the mechanism of siltation is important for the selection of measures to be taken to prevent deposition and for estimating the siltation volume that will develop when planning ports and harbors.

Fig.1 shows an outline of the above-mentioned siltation mechanism. This paper describes the necessity of measuring relevant factors and the proper measurement methods for a siltation field survey.

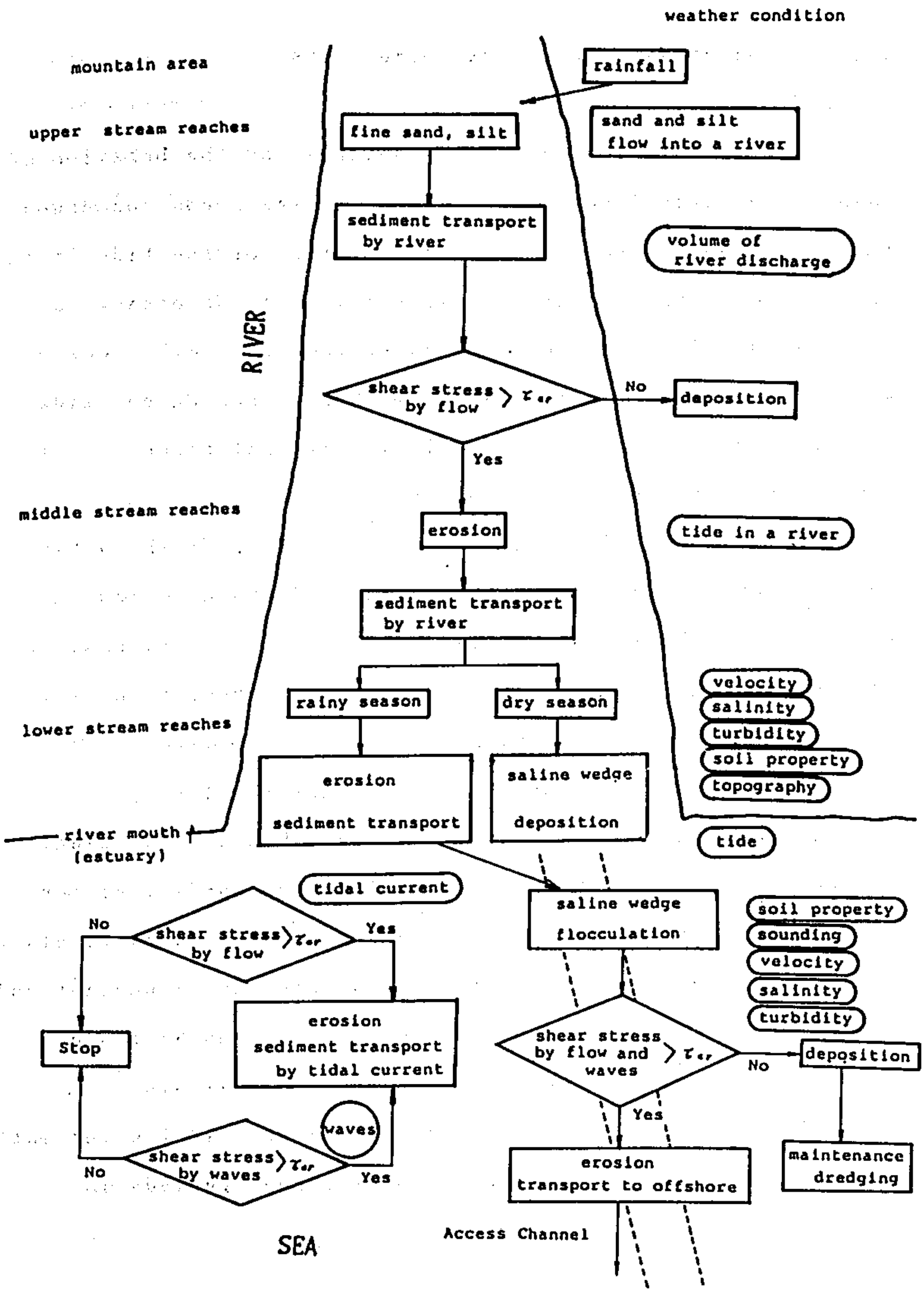

Fig. 1 The outline of mechanism of siltation

2.1 Acquisition of data on natural conditions

(a) Tide

Tide is a basic factor when determining the behavior of changes in water levels and currents in sea areas concerned. In order to understand the characteristics of the tide in the sea area concerned, meant the grasping it is necessary to measure the distance from the sea surface to the bottom, which varies momentarily (water depth). Furthermore, tide is the most important factor that is an external force generating currents in the sea area.

Tide can be defined as the rise and fall of the water surface level accompanied by movements of the moon and the sun. Tidal behavior is regular. Therefore, it is possible to know the characteristics of tide and to predict the level of the water surface by using its harmonic constants.

The harmonic components of tide consist of many periods ranging from one year to several hours. The tidal harmonic components shown in Table 1 [1] are sufficient for performing analyses for engineering purposes. In particular, the four components marked with an asterisk are important and are called the four main tidal components. The harmonic constants of tide are obtained by harmonic analysis. Harmonic analysis is a method that separates tidal waves into several tidal wave components with different periods in order to obtain the amplitudes and phase lags of each tidal wave component. The number of tidal components separated by such analysis is limited by the duration of the observation period. Data on tidal levels is a basic factor in studying about the natural conditions or the sea area of interest. Therefore, it is desirable that the observation period be as long as possible. A fairly accurate harmonic analysis can be made if data for at least one year is provided. The harmonic constant, once calculated, does not change so much even if there is some change in the conditions.

Generally speaking, tidal levels are measured by continuously observing the rise and fall of the water surface in a tide gauge well over a long period. Therefore, it is desirable that tidal levels be observed for a long period, such as several years, with a facility based on strong foundations. However, if data is required urgently or if a short observation period is enough to provide adequate data, a throw-in type tidal gauge can be used to observe the tide level.

If the observation area is not large and if the currents are not very complex, one observation station is enough to measure tide levels. The boundary conditions of tidal levels in the sea area of interest are considered with reference to tidal level records of other neighbouring sea areas. However, if the sea area of interest is large, or if the currents are complex and there is a long tidal river, two or more observation stations are required.

Using the above-mentioned type of tidal data, the harmonic constants of a tide shown in Table 2 and a diagram of the height of its tidal levels as shown in Fig. 2 can be obtained.

Table 1 Main Components of tide and Its phase Velocity

Component	Phase Velocity
S_a	0.041067
S_{sa}	0.082137
Q_1	13.398661
O_1*	13.943036
P_1	14.958931
K_1*	15.041069
μ_2	27.968208
N_2	28.439730
ν_2	28.512583
M_2*	28.984104
L_2	29.528479
S_2*	30.000000
K_2	30.082137
M_4	57.968208
MS_4	58.984104

*The four main tidal components

Table 2 Harmonic Constants of Tide in Kumamoto Port

Component	Amplitude (cm)	Lag (degree)
S_a	17.64	140.64
S_{sa}	4.47	20.70
Q_1	4.19	189.60
O_1*	21.17	197.30
P_1	8.78	217.10
K_1*	28.06	217.48
μ_2	9.48	308.77
N_2	25.36	252.30
ν_2	3.95	229.51
M_2*	134.68	255.08
L_2	7.13	224.67
S_2*	57.90	290.68
K_2	15.33	282.85
M_4	0.73	321.14
MS_4	0.69	326.24

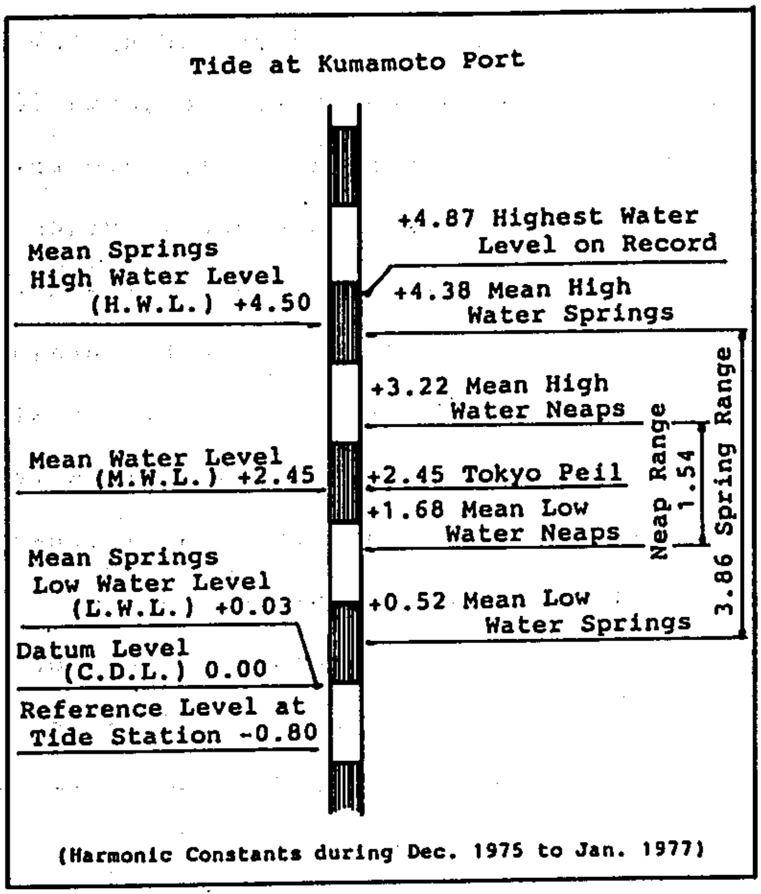

Fig. 2 Tidal Levels in Kumamoto Port.

(b) Wind

Wind is an external force that generates waves. It is also an external force that generates currents. Therefore, wind is an important factor in understanding the natural conditions of the sea area concerned. Observation data on winds measured over a long period of time are preserved at meteorological observatories. However, as winds on land are apt to be influenced by the topography of the area such as mountains or buildings, it is desirable to obtain measurements of winds on the sea area of interest. Data on winds is generally used for the values at 10 meters above the ground or the sea surface. Therefore, measurements of wind should be made 10 meters above the sea surface.

Wind data is analyzed in terms of annual or seasonal the distributions of frequency of of winds as classified according to wind direction or wind velocity as shown in Table 3, and in terms of wind rose as shown in Fig.3. Wind directions are utilized in some cases to estimate the wave directions in the observational sea area where data on wave directions is not available.

Table 3 Frequencies Distribution Wind Direction and Wind Velocity (1980.1-1984.12)

(unit:frequency, ( ) shows %)

Season	Velocity	CALM	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
Through a year	Calm (less than 0.5m/s)	1,532 (4.0)																	
	0.5- 4.9		1,778 (4.7)	752 (2.0)	412 (1.1)	580 (1.5)	2,460 (6.5)	3,811 (10.1)	1,580 (4.2)	590 (1.6)	578 (1.5)	683 (1.8)	1,048 (2.8)	855 (2.3)	853 (2.3)	1,248 (3.3)	1,551 (4.1)	1,261 (3.3)	21,571 (57.0)
	5.0- 9.9		2,435 (6.4)	832 (2.2)	265 (0.7)	377 (1.0)	1,081 (2.9)	1,362 (3.6)	182 (0.5)	68 (0.2)	584 (1.5)	1,095 (2.9)	1,360 (3.6)	420 (1.1)	197 (0.5)	1,068 (2.8)	1,880 (5.0)	1,395 (3.7)	14,602 (38.6)
	10.0-14.9		232 (0.6)	50 (0.1)	23 (0.1)	64 (0.2)	85 (0.2)	4 (0.0)		25 (0.1)	64 (0.2)	62 (0.2)	155 (0.4)	48 (0.1)	46 (0.1)	201 (0.5)	255 (0.7)	284 (0.7)	1,516 (4.2)
	15.0-19.9		8 (0.0)	2 (0.0)	8 (0.0)					2 (0.0)	2 (0.0)	2 (0.0)	6 (0.0)	4 (0.0)	5 (0.0)	27 (0.1)	14 (0.0)	8 (0.0)	91 (0.2)
	20.0-										6 (0.0)								6 (0.0)
	TOTAL	1,532 (4.0)	4,453 (11.8)	1,636 (4.3)	708 (1.9)	1,021 (2.7)	3,626 (9.6)	5,177 (13.7)	1,762 (4.7)	685 (1.8)	1,234 (3.3)	1,842 (4.9)	2,569 (6.8)	1,327 (3.5)	1,102 (2.9)	2,544 (6.7)	3,700 (9.8)	2,944 (7.8)	37,866 (100.)

Ratio of Data obtained 86.4%

Season	Velocity	CALM	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
Winter Season	Calm (less than 0.5m/s)	412 (4.0)																	
	0.5- 4.9		705 (6.9)	331 (3.2)	156 (1.5)	158 (1.6)	625 (6.1)	1,152 (11.3)	560 (5.5)	220 (2.2)	107 (1.0)	46 (0.4)	59 (0.6)	73 (0.7)	79 (0.8)	188 (1.8)	42 (3.4)	362 (3.5)	5,576 (54.6)
	5.0- 9.9		1,184 (11.6)	374 (3.7)	75 (0.7)	44 (0.4)	243 (2.4)	536 (5.3)	59 (0.6)	16 (0.2)	40 (0.4)	30 (0.3)	30 (0.3)	55 (0.5)	69 (0.7)	226 (2.2)	511 (5.0)	594 (5.8)	4,085 (40.0)
	10.0-14.9		95 (0.9)	12 (0.1)		6 (0.1)					2 (0.0)	6 (0.1)	8 (0.1)	2 (0.0)	10 (0.1)	85 (0.5)	139 (1.4)	174 (1.7)	532 (5.3)
	15.0-19.9														2 (0.0)	4 (0.0)	2 (0.0)	4 (0.0)	12 (0.1)
	20.0-																		
	TOTAL	412 (4.0)	1,984 (11.4)	717 (7.0)	231 (2.3)	208 (2.0)	868 (8.5)	1,682 (16.5)	619 (6.1)	236 (2.3)	149 (1.5)	82 (0.8)	97 (0.9)	130 (1.3)	160 (1.6)	503 (4.9)	994 (9.7)	1,134 (11.1)	10,211 (100.)

Ratio of Data obtained 94.1%

Season	Velocity	CALM	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
Summer Season	Calm (less than 0.5m/s)	401 (4.4)																	
	0.5- 4.9		91 (1.0)	41 (0.4)	56 (0.6)	83 (0.9)	529 (5.8)	828 (9.0)	347 (3.8)	104 (1.1)	228 (2.5)	274 (3.0)	450 (4.9)	309 (3.4)	342 (3.7)	432 (4.7)	338 (3.7)	261 (2.8)	5,113 (55.7)
	5.0- 9.9		81 (0.9)	39 (0.4)	73 (0.8)	174 (1.9)	332 (3.6)	201 (2.2)	48 (0.5)	12 (0.1)	309 (3.4)	664 (7.2)	782 (8.5)	181 (2.0)	27 (0.3)	226 (2.5)	301 (3.3)	228 (2.5)	3,677 (40.1)
	10.0-14.9		6 (0.1)	6 (0.1)	21 (0.2)	54 (0.6)	79 (0.9)	4 (0.0)		10 (0.1)	37 (0.4)	25 (0.3)	56 (0.6)	17 (0.2)	2 (0.0)	4 (0.0)	6 (0.1)	21 (0.2)	347 (3.8)
	15.0-19.9		6 (0.1)	2 (0.0)	8 (0.1)						2 (0.0)	2 (0.0)	6 (0.1)	4 (0.0)			4 (0.0)		33 (0.4)
	20.0-										6 (0.1)								
	TOTAL	401 (4.4)	184 (2.0)	88 (0.9)	158 (1.7)	311 (3.4)	940 (10.2)	1,033 (11.3)	395 (4.3)	126 (1.4)	582 (6.3)	965 (10.5)	1,294 (14.1)	511 (5.6)	371 (4.0)	662 (7.2)	649 (7.1)	510 (5.6)	9,176 (100.)

Ratio of Data obtained 83.1%

Data : From "Wind Observation Result at Kumamoto Port" by 4th District Port Construction Bureau, *Ministry of Transport and Yatsushiro Port Construction Office*

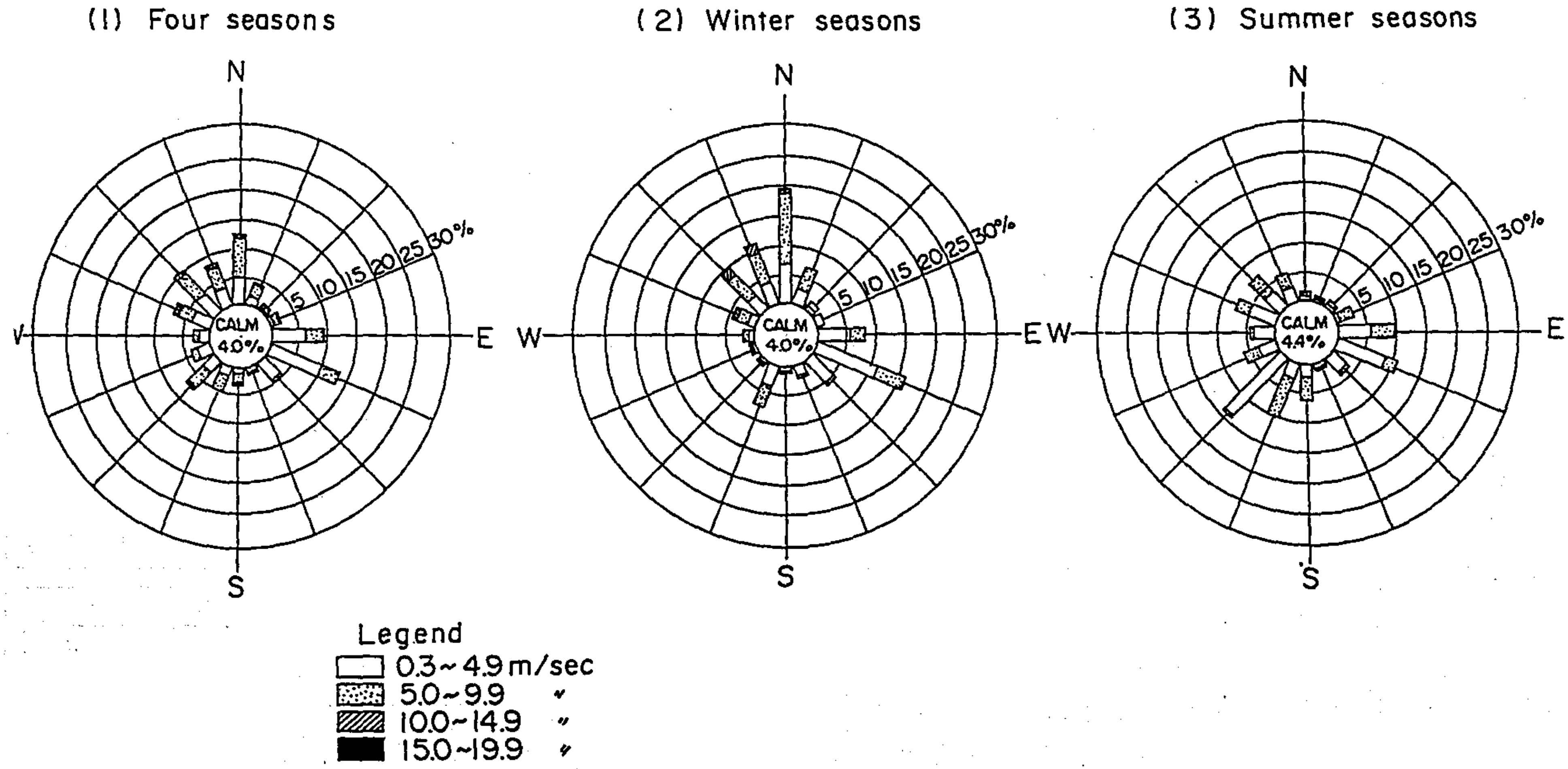

Fig. 3 Frequencies Distribution of Wind Directions by Wind Velocity

(c) Wave

The wave action is the strongest external force responsible for the suspension of bottom sediment in the coastal area. Furthermore, waves contribute to the transportation of bottom sediment by generating longshore currents due to radiation stress. Therefore, when studying the problem of siltation, it is most important to observe the characteristics of waves in the sea area concerned.

Waves are generated, developed and propagated by the tangential stress of winds that blow over the sea surface. Therefore, wind velocities, wind directions and the influence of winds in the surrounding sea area are the most important factors for characterizing waves. Therefore, it is necessary to obtain data on winds at the same time when the waves are measured.

Waves are measured by a wave gauge. Waves are specified by wave height, wave period and wave direction. Waves are transformed by configuration, topography and water depth. Therefore, in order to obtain the characteristics of waves in the entire area of interest, it is desirable to measure the deep water waves, which are not affected by bottom configurations. However, so far as the problem of siltation is concerned, the shearing stress of waves on the bottom surface is considered to be an important external force acting on bottom sediment in the sea area. Thus, it is necessary to measure waves in the shallow sea area of interest. Furthermore, if bottom sediments with a high water content are deposited on the sea bottom, the bottom sediments move in a wave motion together with the movement of water waves. There is also the phenomenon of wave heights damping together with the dissipation of wave energy. In order to calculate the distributions of wave heights in the entire area of interest, it is necessary to obtain not only data on the transformation of waves, but also this damping coefficient. The damping rate of wave heights can be calculated by obtaining wave heights at two points in the wave's propagation direction.

Various types of wave gauges are available. A shooting type ultrasonic wave gauge was used for wave height observation in the Banjarmasin study. Wave heights and periods are measured with a wave gauge. At present, various kinds of wave direction meters have been developed.

At present, the directions of waves with a long period are estimated from off-shore data and those of waves with a short period are estimated by observing wind directions.

Data processing of the measured values of waves is classified into annual statistical data and specialized data for stormy weather wave characteristics and other conditions.

Table 4 shows the frequency distributions of waves classified by wave direction and wave height Fig. 4 is a diagram of the frequency distributions of waves, respectively, in Kumamoto Port in 1979-1982 and in 1985. Table 5 shows the frequency distributions of waves classified by wave height and wave period in the same observation period. Here, wave directions are estimated from records on wind directions. Although it is not treated here, the problem of statistical data on wave height is an important issue in the processing of records of wave data.

Next, there is the problem of wave characteristics in stormy weather. In cases where the behavior of bottom sediment is affected largely by waves as in Kumamoto Port, simultaneously recorded data on wave heights, tidal levels, currents, water particle velocity (current), turbidity (SS) and deposition height in stormy weather are important data for analyzing the mechanism of siltation. Fig. 5 shows results of the observation data as an example. It is clear from this figure that the oscillating flow velocity on the bottom surface (or the shearing stress on the bottom surface) increases when wave heights are large and the tidal level is low, and as a result of that, SS concentration is increased and the sedimentation thickness is increased.

Table-4 Appeared Frequency of Wave Direction and Wave Height (1979-82, 1985)

Upper layer : Appeared times

Middle layer: % (Appeared times / Total times)

Lower layer : % (Appeared times / Rank total)

Wave direction / Wave height	CALM	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
CALM	14370 76.1 100.								14370 76.1 100.
0.0<H<0.2	7 0.0 29.1	3 0.0 12.5	3 0.0 12.5			4 0.0 16.7	6 0.0 25.0	1 0.0 4.2	24 0.1 100.
0.2≦H<0.4	743 3.9 47.4	143 0.8 9.1	131 0.7 8.3	68 0.4 4.3	29 0.2 1.8	86 0.5 5.5	193 1.0 12.3	178 0.9 11.3	1571 8.3 100.
0.4≦H<0.6	715 3.8 38.3	127 0.7 6.8	155 0.8 8.3	70 0.4 3.7	33 0.2 1.8	176 0.9 9.4	304 1.6 16.3	288 1.5 15.4	1868 9.9 100.
0.6≦H<0.8	214 1.1 33.3	19 0.1 2.9	48 0.3 7.4	25 0.1 3.9	18 0.1 2.8	78 0.4 12.1	97 0.5 15.0	146 0.8 22.6	645 3.4 100.
0.8≦H<1.0	59 0.2 22.7	2 0.0 0.8	11 0.1 4.2	13 0.1 5.0	10 0.1 3.8	42 0.2 16.2	72 0.4 27.7	51 0.3 19.6	260 1.4 100.
1.0≦H<1.2	16 0.1 17.8	1 0.0 1.1	1 0.0 1.1	2 0.0 2.2	5 0.0 5.6	19 0.1 21.1	17 0.1 18.9	29 0.2 32.2	90 0.5 100.
1.2≦H<1.4	6 0.0 16.3	1 0.0 2.7		2 0.0 5.4	1 0.0 2.7	6 0.0 16.2	11 0.1 29.7	10 0.1 27.0	37 0.2 100.
1.4≦H<1.6					1 0.0 12.5		1 0.0 12.5	6 0.0 75.0	8 0.0 100.
1.6≦H<1.8								2 0.0 100.	2 0.0 100.
1.8≦H									
TOTAL	16,130 85.4 85.4	296 1.6 1.6	349 1.8 1.8	180 1.0 1.0	97 0.5 0.5	411 2.2 2.2	701 3.7 3.7	711 3.8 3.8	18875 100. 100.

(Remark) In case of no data for wind direction, data were excluded.

Table 5 Table of Frequencies by Wave Height and by Period (1979-1982 and 1985)

Period(SEC) \ Wave height (m)		CALM	0.0<H <0.2	0.2≦H <0.4	0.4≦H <0.6	0.6≦H <0.8	0.8≦H <1.0	1.0≦H <1.2	1.2≦H <1.4	1.4≦H <1.6	1.6≦H <1.8	1.8≦	TOTAL
CALM	Times %	14370 74.2											14370 74.2
T<1.0	Times %												
1.0≦T<2.0	Times %		4 0.0	33 0.2									34 0.2
2.0≦T<3.0	Times %		24 0.1	1320 6.8	1063 5.5	149 0.8	8 0.0						2564 13.2
3.0≦T<4.0	Times %		3 0.0	371 1.9	905 4.7	519 2.7	225 1.2	52 0.3	15 0.1				2090 10.8
4.0≦T<5.0	Times %			39 0.2	72 0.4	57 0.3	40 0.2	33 0.2	22 0.1	8 0.0	2 0.0		273 1.4
5.0≦T<6.0	Times %		2 0.0	8 0.0	11 0.1	7 0.0	3 0.0	2 0.0	1 0.0		1 0.0		35 0.2
6.0≦T	Times %				2 0.0	2 0.0	1 0.0	3 0.0					8 0.0
TOTAL	Times %	14370 74.2	33 0.2	1768 9.1	2053 10.6	734 3.8	277 1.4	90 0.5	38 0.2	8 0.0	3 0.0		19374 100.0

(note) Data included at the time of no data for wind direction.

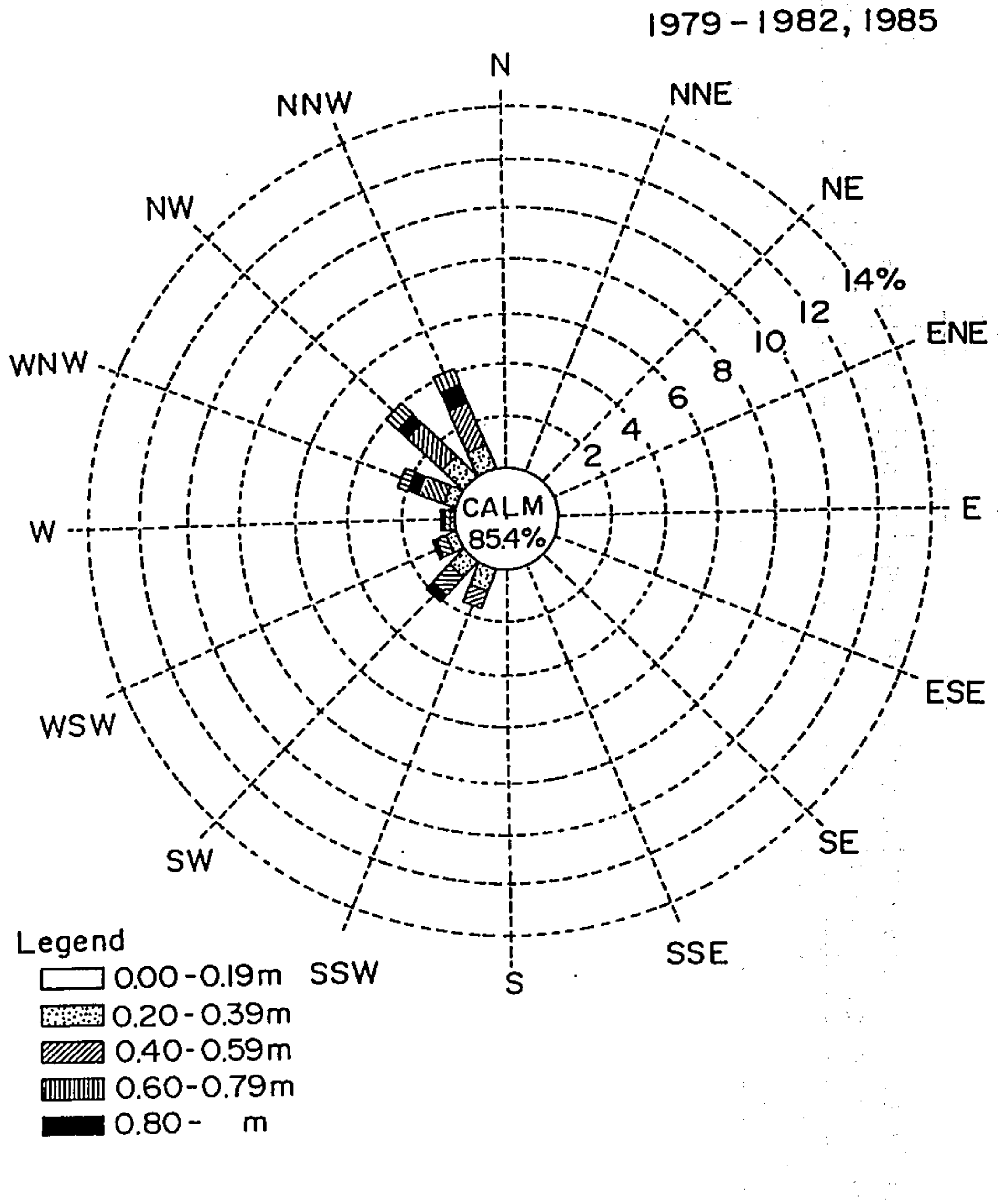

Fig. 4 Frequencies Distribution of Wave Directions by Wave Height

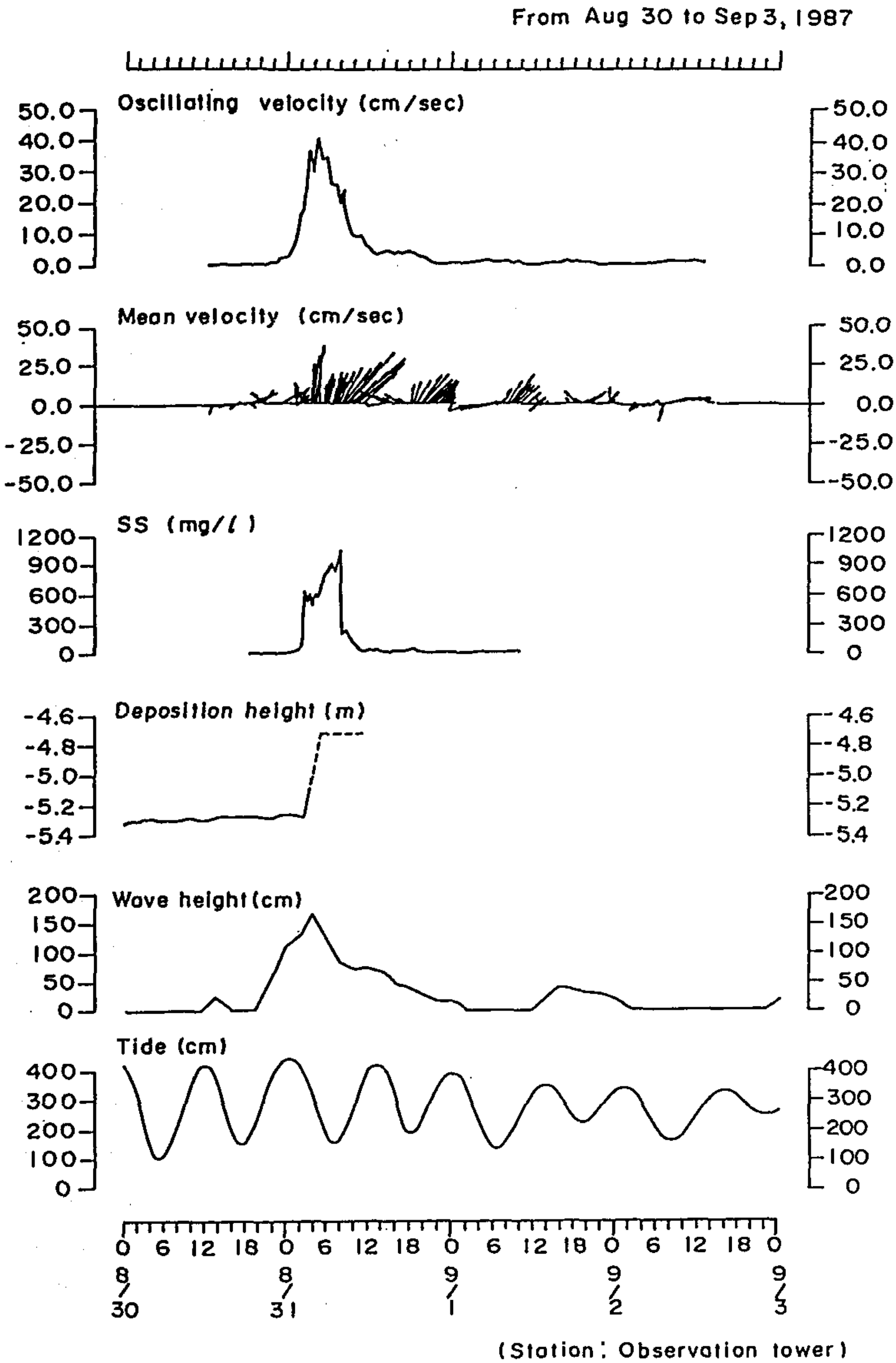

Fig. 5 Simultaneously Recorded Data on Oscillatry Flow Velocity, Average Flow Velocity, Turbidity, Deposition Height, Wave Height and Tide (Kumamoto)

(d) Current

In the observation of currents, they are classified into relatively large-scale waves, such as tidal currents, longshore currents due to waves, and oscillating currents due to the movement of water particles from wave action. Suspended material eroded from the bottom sediment by waves or currents is thought to be carried by tidal currents. In order to obtain the sediment deposition direction, it is necessary to study the behavior of tidal currents in the sea area of interest.

Tidal currents are generated by tides, and their movement is very regular. Therefore, harmonic analysis is effective for understanding the behavior of tidal currents in the sea area of interest, just as it is for tide. However, tidal currents are influenced more by external factors than tides, which are influenced by the movements of heavenly bodies. Some examples are wind-driven currents, density currents, longshore currents and sea currents. Therefore, it is not as simple to discover the behavior of tidal currents as it is for tides. However, in a sea area like Kumamoto Port, where the tidal range is large and where there is only a narrow mouth open to the sea, or in sea areas with large tidal rivers like Banjarmasin Port, the tidal component is the most important.

Tidal currents are measured generally by an Ono-type current meter or a Bergen type current meter. As in the case of tide, it is desirable to measure currents for as long as possible. However, it is extremely difficult to do so because of such various problems as the difficulty of mooring a current meter. It is necessary to carry out continuous measurements for at least 15 days - one month in order to obtain a harmonic constant of tidal currents. The measurement point of tidal currents should be chosen in order to make it possible to obtain a general pattern of tidal currents in the sea area concerned. This point should be suitable for use as a boundary in future studies to help verify data for future tidal current simulations. Measurement taken at position which is liable to be affected by eddy currents due to configurations should be avoided, except in cases where data obtained at such a point is of special significance.

Currents in stormy weather should be measured by a different method from that mentioned above. In order to observe the phenomenon of bottom sediment being eroded by the oscillatory current component of waves, or to discover the behavior of fine particles on the sea bottom, it is necessary to measure short period currents, such as the oscillating flow velocity due to wave action near the sea bottom.

together with averaged currents, such as tidal currents. An electromagnetic current meter which can measure in time intervals of 0.5 - 1.0 second is suitable for the purpose of this kind of measurement. Fig.6 shows an electromagnetic current meter installed with its framework on the sea bottom. This measurement method makes it possible to see whether the erosion of bottom sediment is due to waves or tidal currents. Fig.7 shows the relationships between average flow velocity and turbidity (SS), and oscillatory flow velocity and turbidity measured on the sea bottom in Osaka Bay[3].

Tracking floats on the sea surface is a simple way of investigating the pattern of currents in the observational area. A float is liable to be strongly affected by winds. To control cope for the wind effect, the float has a submerged resisting plate, as shown in Fig.8. This allows it to follow the current at the depth of the resisting plate. This method is very simple and makes it possible to observe the flow pattern over a wide sea area. But it is very difficult to carry out continuous, long-term observations under these conditions.

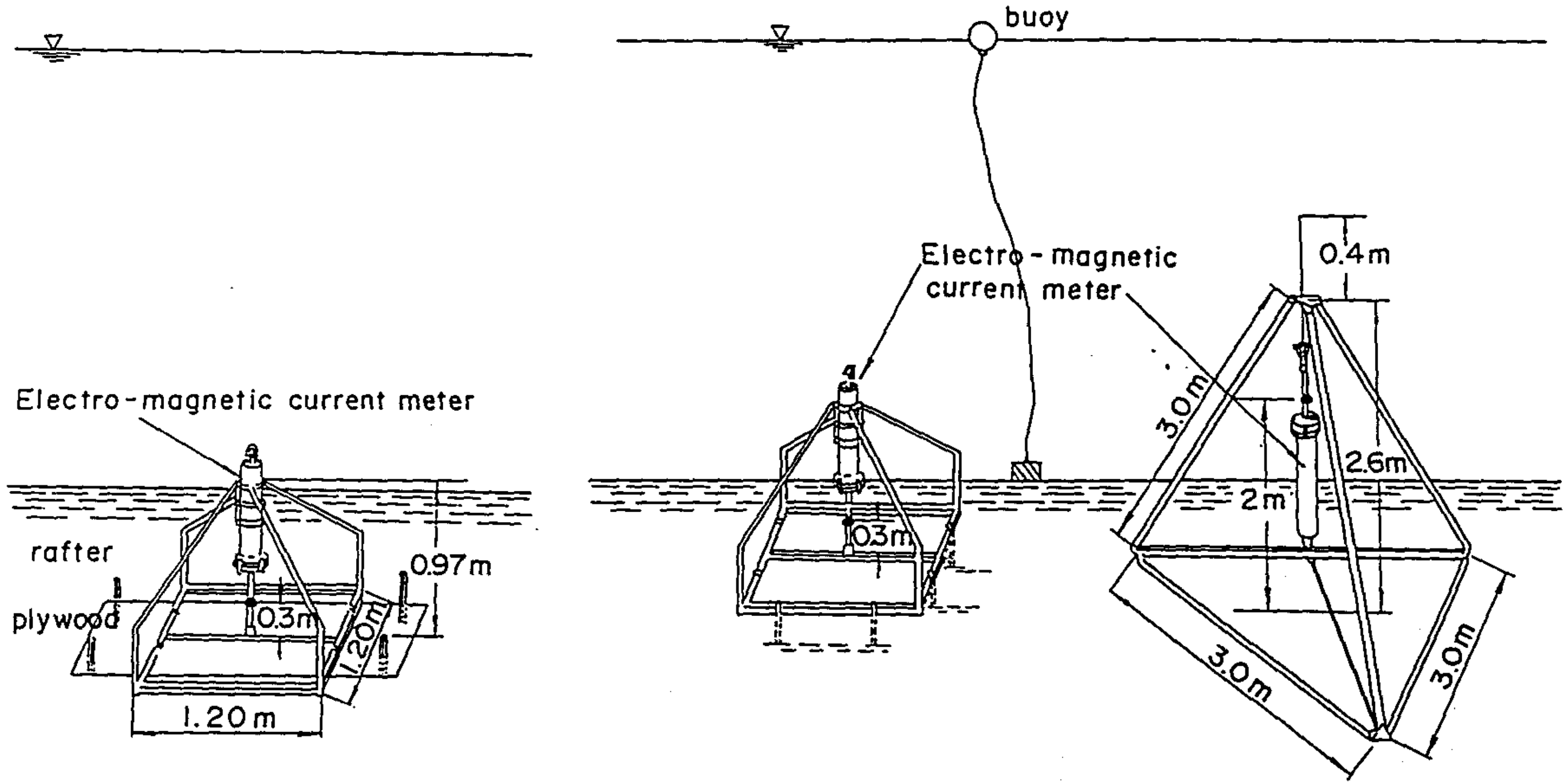

Fig. 6 Installation of an Electromagnetic Current Meter

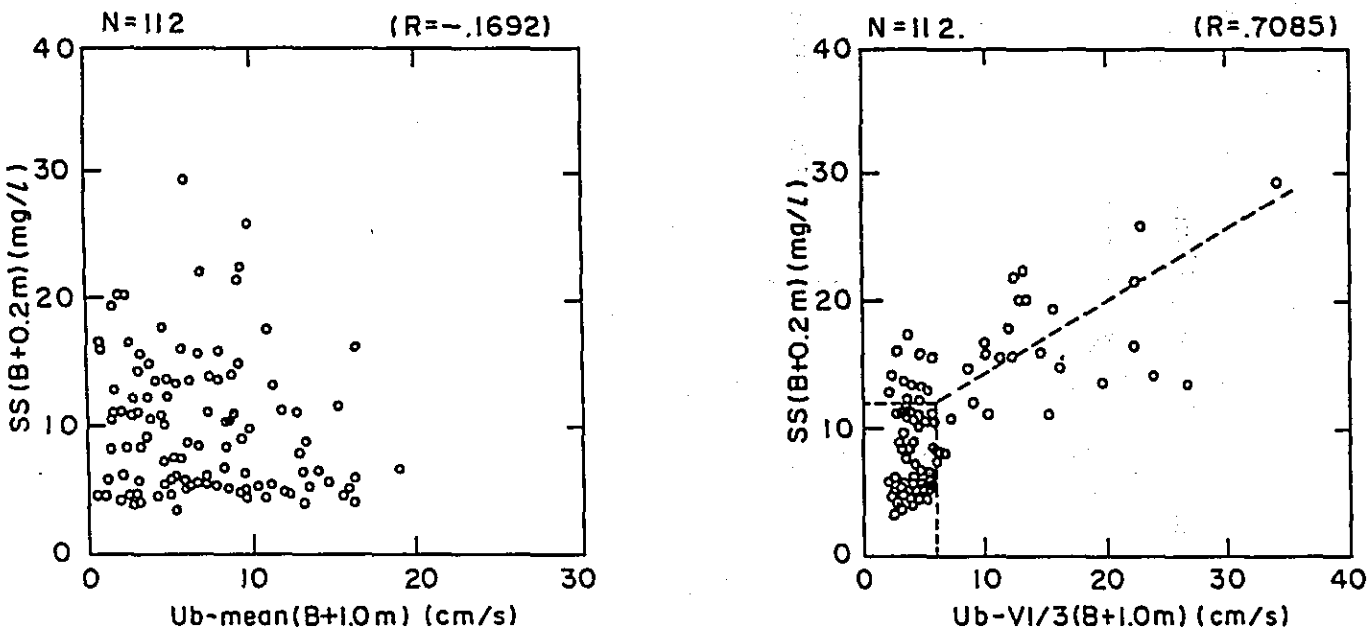

Fig. 7 Average Flow Velocity and Turbidity (left) and the Relationships between Oscillatory Flow Velocity and Turbidity (right)

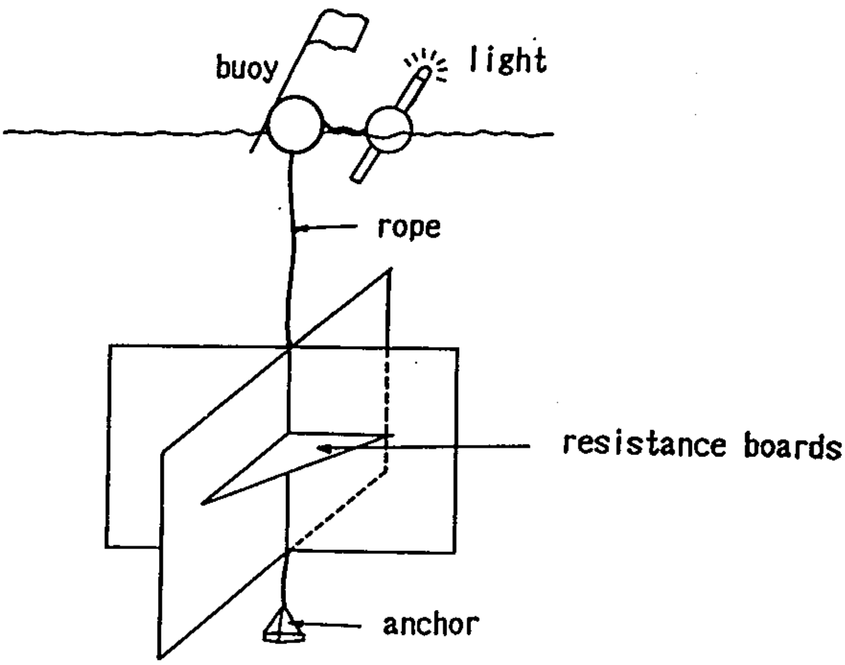

Fig. 8 Sketch of Float

(e) Saline wedge

When clay particles suspended in river water (fresh water) come into contact with sea water, they form flocs and settle down to the bottom because of the existence of positive charged ions in the sea water. This mechanism is outlined in Fig. 9. The place where fresh water comes into contact with saline water determines where suspended materials settle and deposit.

If there is a tidal rise and fall in the estuary or the river, a tidal prism is generated in the tidal river. Saline water intrudes upstream the river by the tidal prism. This phenomenon is classified into a well-mixed, partially-mixed or weakly-mixed estuary depending on the flow discharge from the river and the tidal range in the sea. Furthermore, whether the river water meets the sea water in the river or in the sea, is determined by the amount of river discharge. Generally, fresh water with a light density flows in the upper layer and sea water with a heavy density flows in the lower layer. Therefore, when this phenomenon is called the saline wedge.

Conducting a field survey of a saline wedge, simultaneous measurements of flow velocity and salinity are carried out for each cross-section. Measurements are needed from surface to bottom layers at each measuring point. The saline water moves upstream during flood tide and recedes downstream during ebb tide. Thus, it is necessary to measure the current velocity and salinity during a complete tidal cycle continuously at regular intervals. There is a difference in a place where a saline wedge occurs in the rainy season, which has a large amount of river discharge, and in the dry season, which has only a small amount of river discharge. Therefore, it is necessary to understand the behavior of seasonal changes of the saline wedge. From the results of measurements taken in different seasons with different river discharge levels, a diagrams of the saline wedge can be shown as in Fig.10 [4].

At Banjarmasin Port, it is thought that sediment deposition occurs in the river in the dry season since the saline wedge moves upstream of the Barito River, and that sediment deposition occurs outside of the river in the rainy season, since the saline wedge is pushed from the river to the sea.

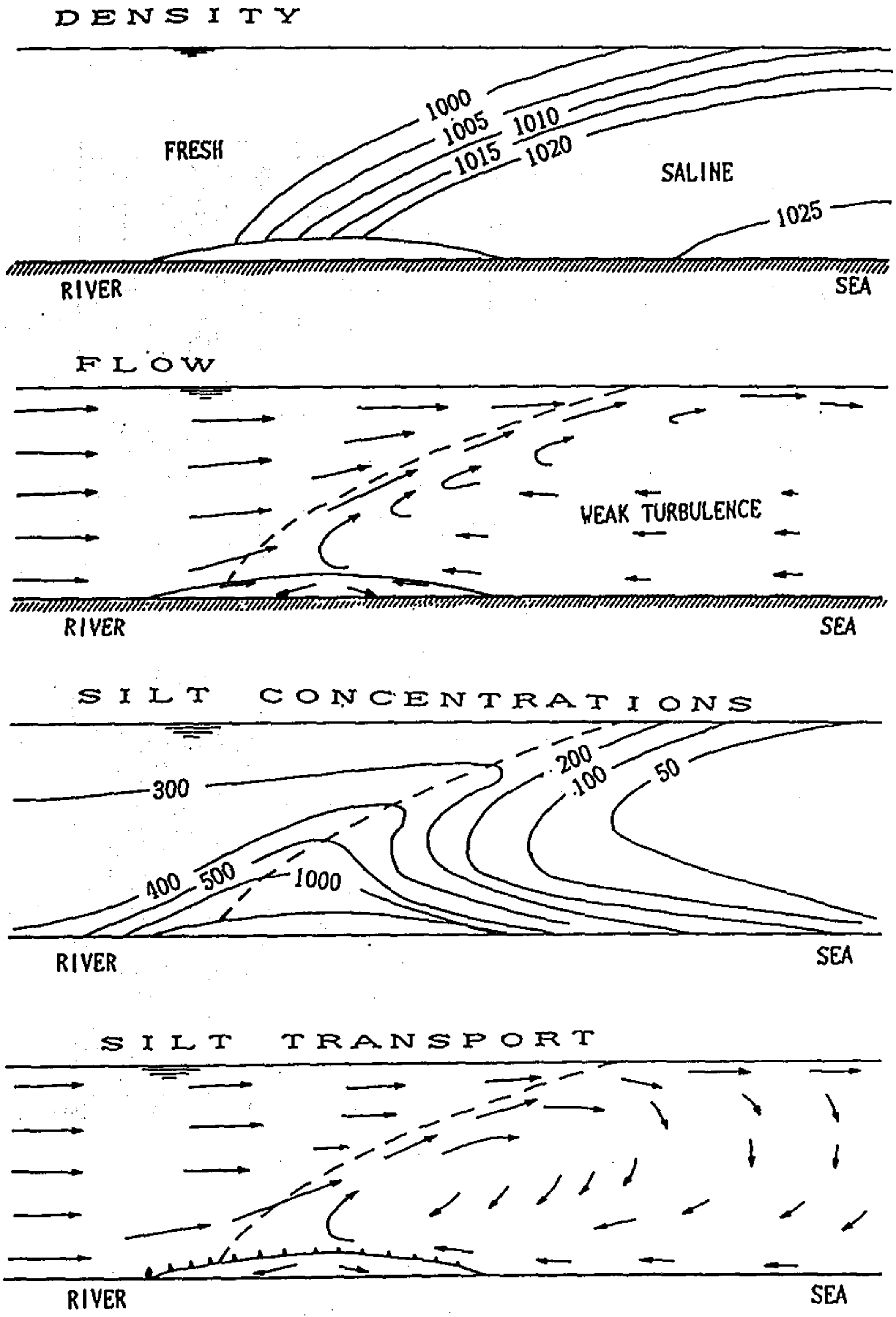

Fig. 9 Mechanisms of Saline Wedge and Siltation

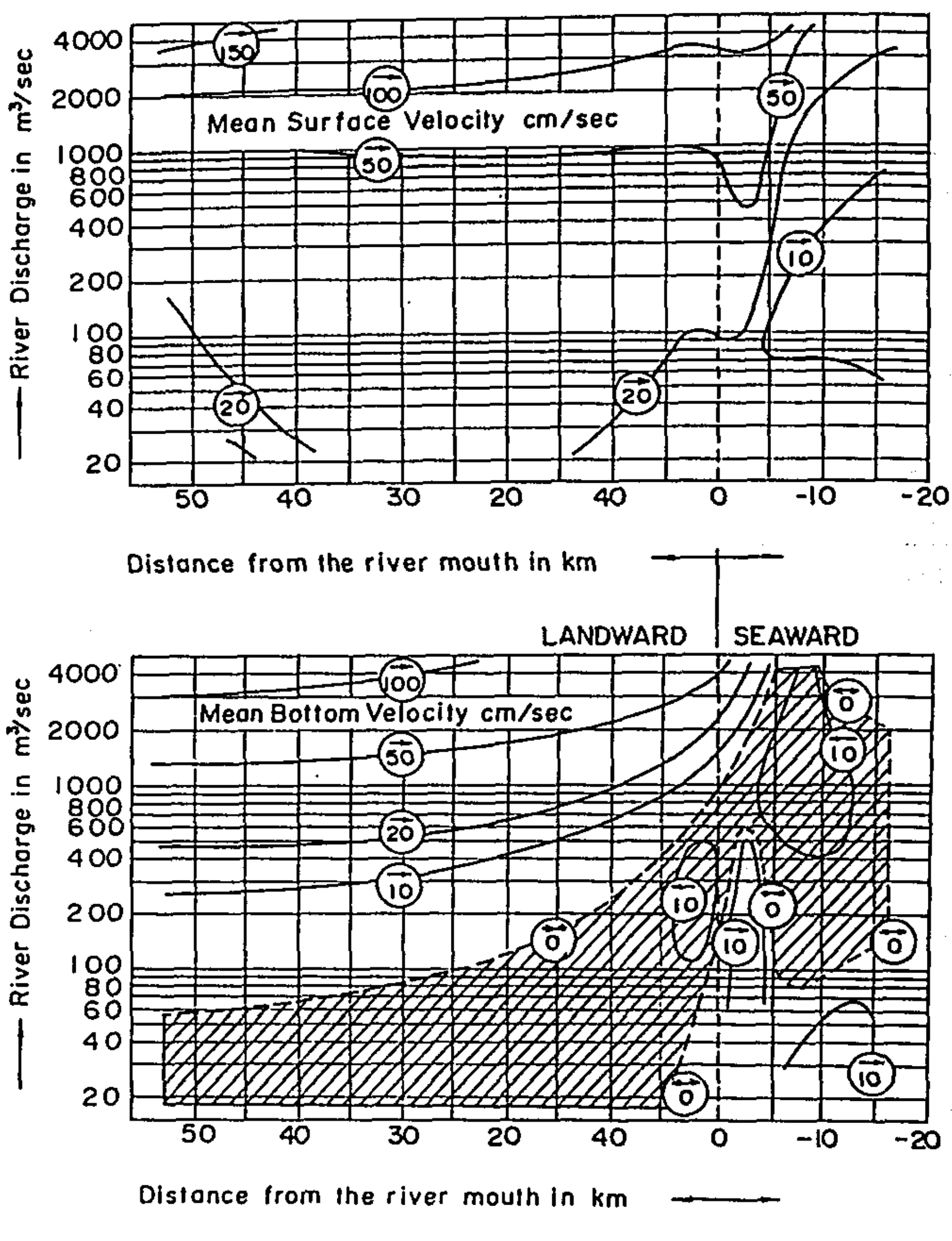

Fig. 10 Relationship between the Flow Directions of the Upper and the Lower Layer of the Chao Phraya River and Its River Discharge

(f) River discharge

The phenomena of tidal current, saline wedge, and the transportation of suspended material in the estuary are affected largely by the amount of river discharge. Therefore, in order to understand the phenomena of natural conditions in the sea area of interest, it is necessary to correctly obtain the amount of river discharge.

Measurements of river discharge are usually carried out at a location further upstream than the area of the tidal river and by obtaining the relationship between water levels and the amount of river discharge. If the tidal river is very long, as for the Barito River, or if there are many tributaries, this method cannot be adopted. In this case, therefore, the river discharge is estimated by measuring the current velocity at the cross-section for the river for a complete tidal cycle, and the average volume of discharge during one tidal cycle is regarded as the river discharge. In order to estimate the river discharge accurately, it is necessary to measure the current velocity for one tidal cycle with a current meter used continuously over the entire cross-section in vertical and horizontal directions.

2.2 Acquisition of data on soil properties

(a) Concentration of suspended materials

Until now we have examined various factors in the research of natural conditions as external forces on siltation. It is important to understand the property of suspension of bottom sediments under various natural conditions. Particularly, it is important to know the vertical distribution of the concentrations of suspended material, in order to understand the mechanisms of the behavior of sediment erosion from the sea bottom and the factors related to the transportation of suspended materials, as well as those involved in the deposition of the material on the sea bottom. This is also useful when carrying out numerical simulations. Therefore, it is necessary to investigate the suspended characteristics of bottom sediment, as well as performing a field survey on various natural conditions.

To begin with, as field measurements for studying the suspended characteristics of bottom sediments, concentration distributions of suspended materials under various natural conditions are measured in the observational area. Turbidity and/or suspended solids are generally measured in order to learn the distributions of suspended materials.

First of all we shall examine the measurements of concentration distributions of suspended material with the use of a turbiditymeter. The turbiditymeter uses an optical system of the backward scattering infrared ray method.

Water is sampled to measure the concentration of suspended solids. Turbidity is strongly related to suspended solids. However, even if the concentration of suspended solids is the same, the turbidity varies due to the distribution characteristics of grain size. While turbidity is obtained by measuring the concentration of suspended solids indirectly with the use of an optical measuring instrument, the measurement of suspended solids by water sampling is a direct method in which the weight of suspended materials in water is measured. This can be used for the verification of the measurement values by a turbiditymeter. Water sampling is done by a water sampler. Water sampling is usually conducted by a water sampler thrown into the sea from a boat. However, this method cannot be performed in stormy weather. In view of the importance of learning the concentration of suspended material in stormy weather for siltation research, an automatic water sampler with a remote timer was used for water sampling in Kumamoto Port. Fig.11 shows the outline of data acquired by a turbiditymeter and a water sampler installed on the observation tower. These are designed for automatic observation and automatic water sampling in stormy weather and are activated by remote-control.

Fig. 12 shows the results of time-series values of measurements of the vertical distribution of turbidity obtained by this facility[2].

Measurements of grain size distribution and ignition loss of the suspended material obtained by water sampling are useful data for discovering the behaviors of erosion and deposition of bottom sediments.

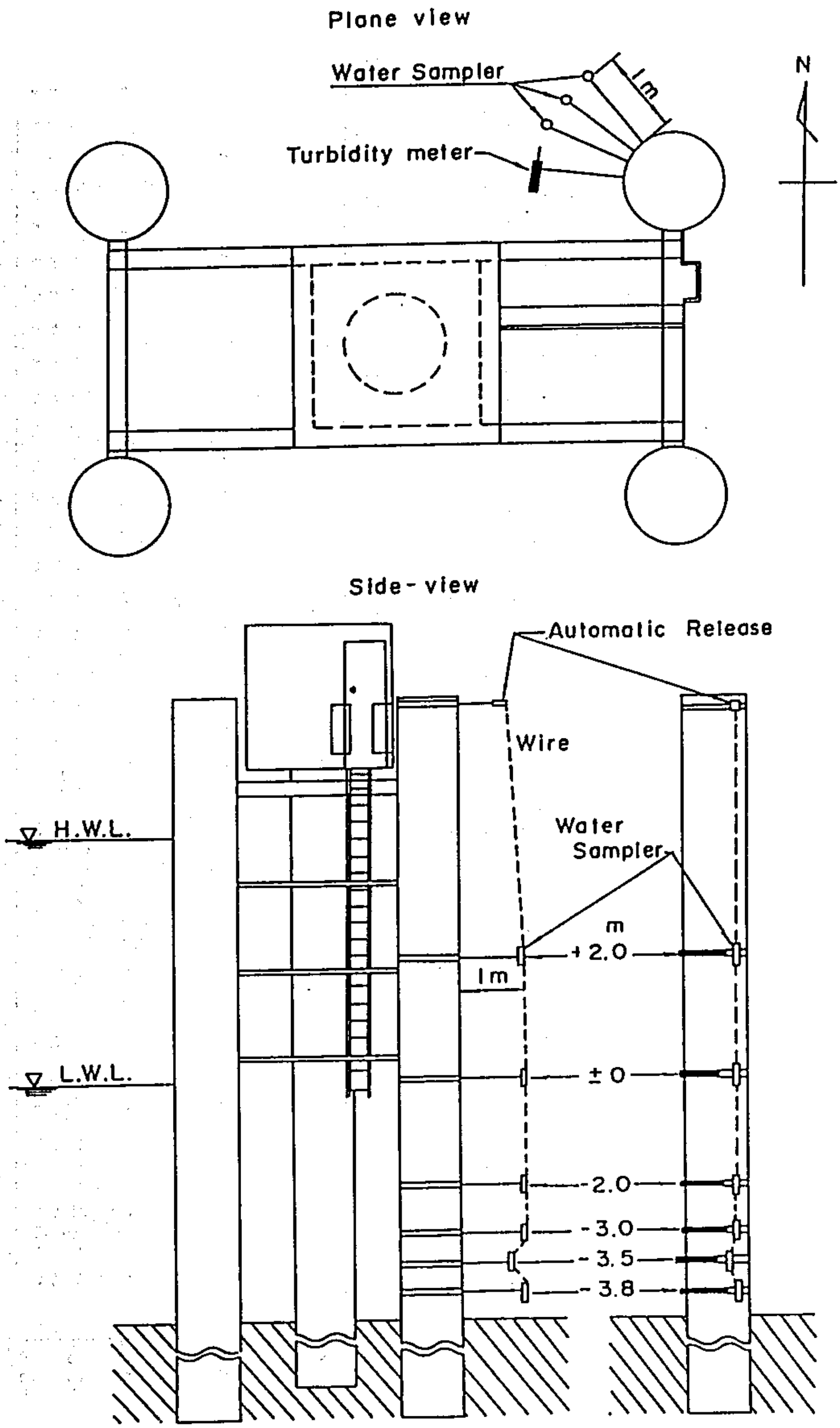

Fig. 11 Water Sampler and Turbiditymeter Installed on the Observation Tower (Kumamoto)

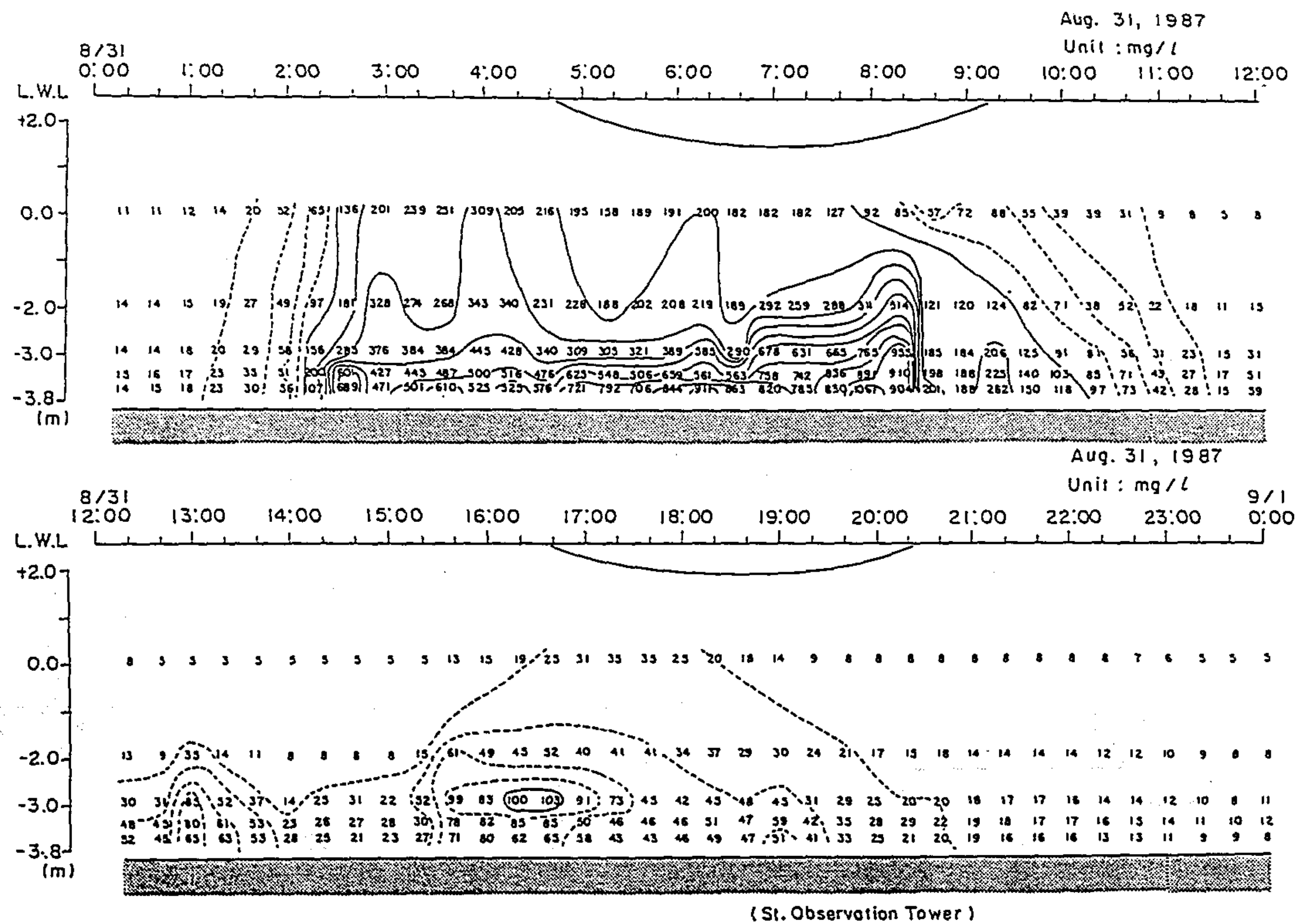

Fig. 12 The observed value of Vertical Distribution of Turbidity

(b) Settling characteristics

Settling characteristics of fine particles are considerably complex. Generally, the settling velocity of a single particle is expressed by the relationship between grain size and settling velocity, as expressed by Stokes' equation. However, cohesive fine particles such as clay and silt do not settle singly or independently, but in the form of flocs. It is well known that the settling velocity of flocs is considerably high when compared to a single particle. Fig.13 shows the relationship between settling velocity and the concentration of suspended solids[5]. If there is a low concentration, the settling velocity increases as the concentration increases. This is due to the fact that as the concentration of suspended material increases, the probability of collision of particles increases and there is an increase in the number of large flocs. However, if the concentration is increased further, the settling velocity is reduced due to interference between particles (hindered settling). For the above reasons, flocculation is a very important factor in the settling velocity of suspended sediments. In the process of flocculation, the size of the flocs is determined by the turbulent intensity of the flow, as well as the above-mentioned concentration. The strength of the turbulent intensity of the flow promotes the formation of flocs as it increases the likelihood of collision of particles. However, it also destroys the large flocs with its shear stress. As explained above, this phenomenon is quite complex.

The problem of settling velocity of sediment particles in siltation is very complex. Attempts at insitu measurement have been made to measure the settling velocity of sediment particles directly. One example is a method called the Owen Tube[6]. The Owen tube combines a water sampler with a sedimentation cylinder, and makes it possible to take water samples and conduct the settling velocity test on a boat immediately afterwards. This means that the measurement size of the flocs is equal to that in the field. Fig.14 shows a Bray Stoke, an insitu type settling velocity equipment of the same type as the Owen tube. In a settling velocity test on a boat, the test tube is stood up as shown in Fig.15. An amount of water equal to one-eighth of the volume of the tube is withdrawn from the bottom of the tube at the designated time, and the settling velocity insitu is estimated from the values of the concentration of suspended solids in the water samples. We should note that this method has the defect that there is a possibility of residual mud particles remaining on the bottom of the tube (in the test conducted in Kumamoto mud particles remained on the bottom surface of the tube). The concentration of mud particles is measured by withdrawing water from the bottom of the tube. To remove this defect, an insitu type settling velocity device has recently been developed. It is designed to allow water to be withdrawn from the side of the tube[7].

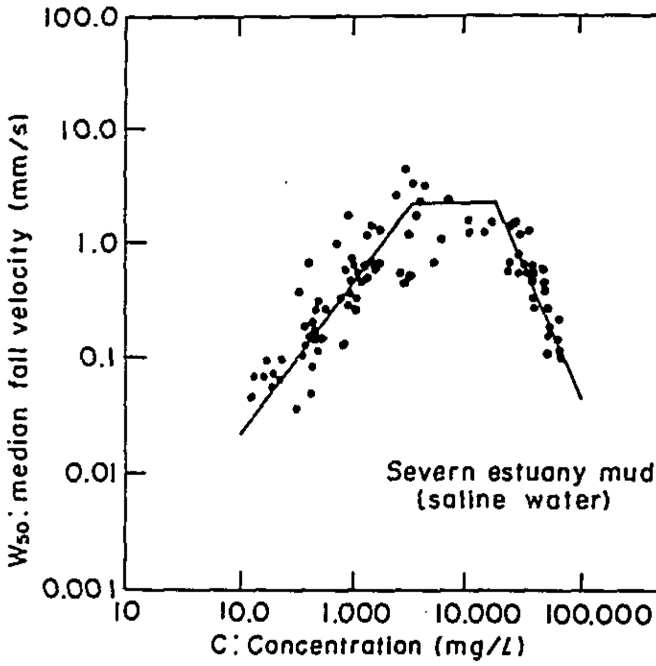

Fig. 13 The Relationship between Concentration of Suspended Materials and Settling Velocity

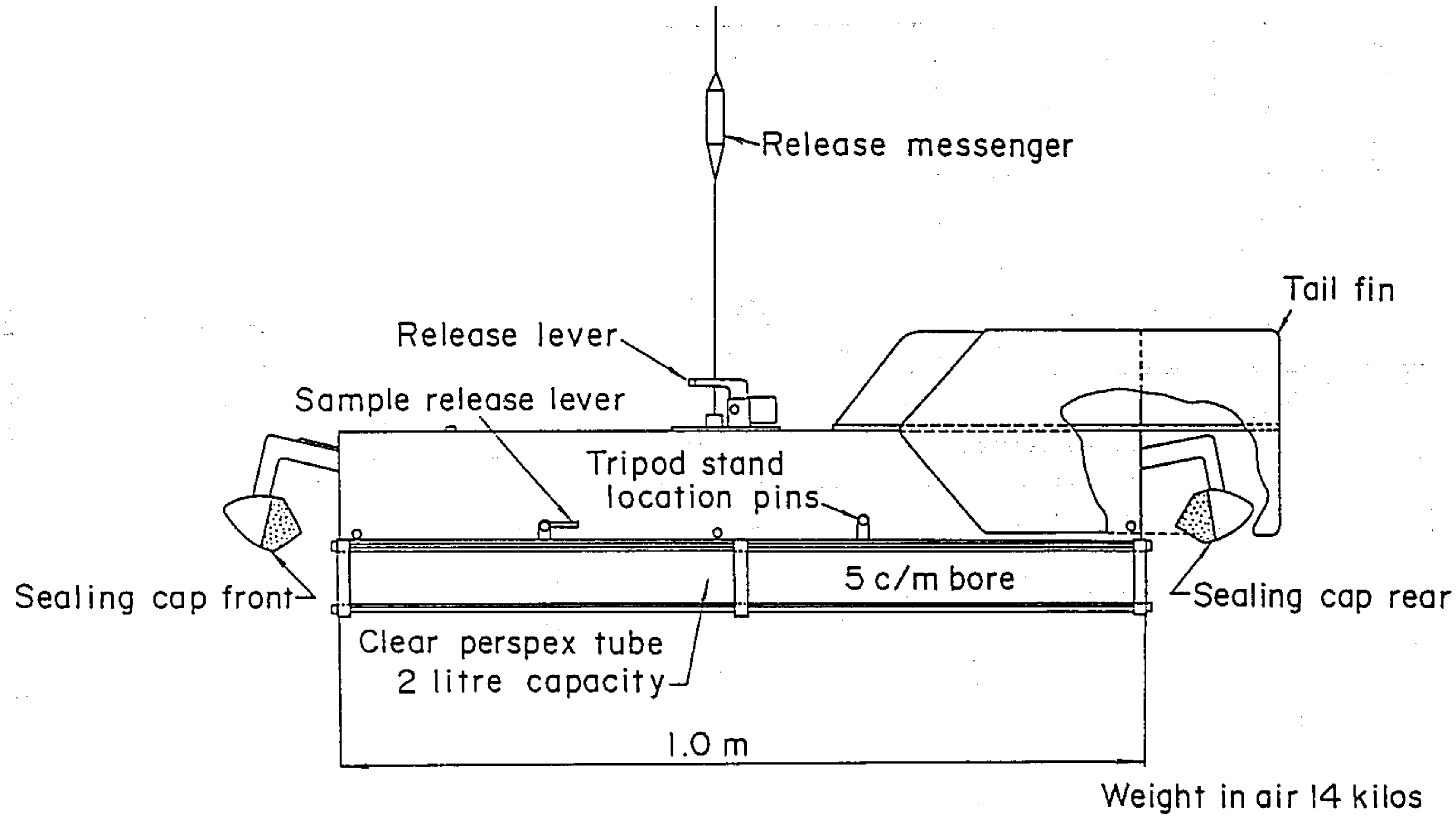

Fig. 14 Owen Tube Type In-Situ Settling Velocity Equipment (in water)

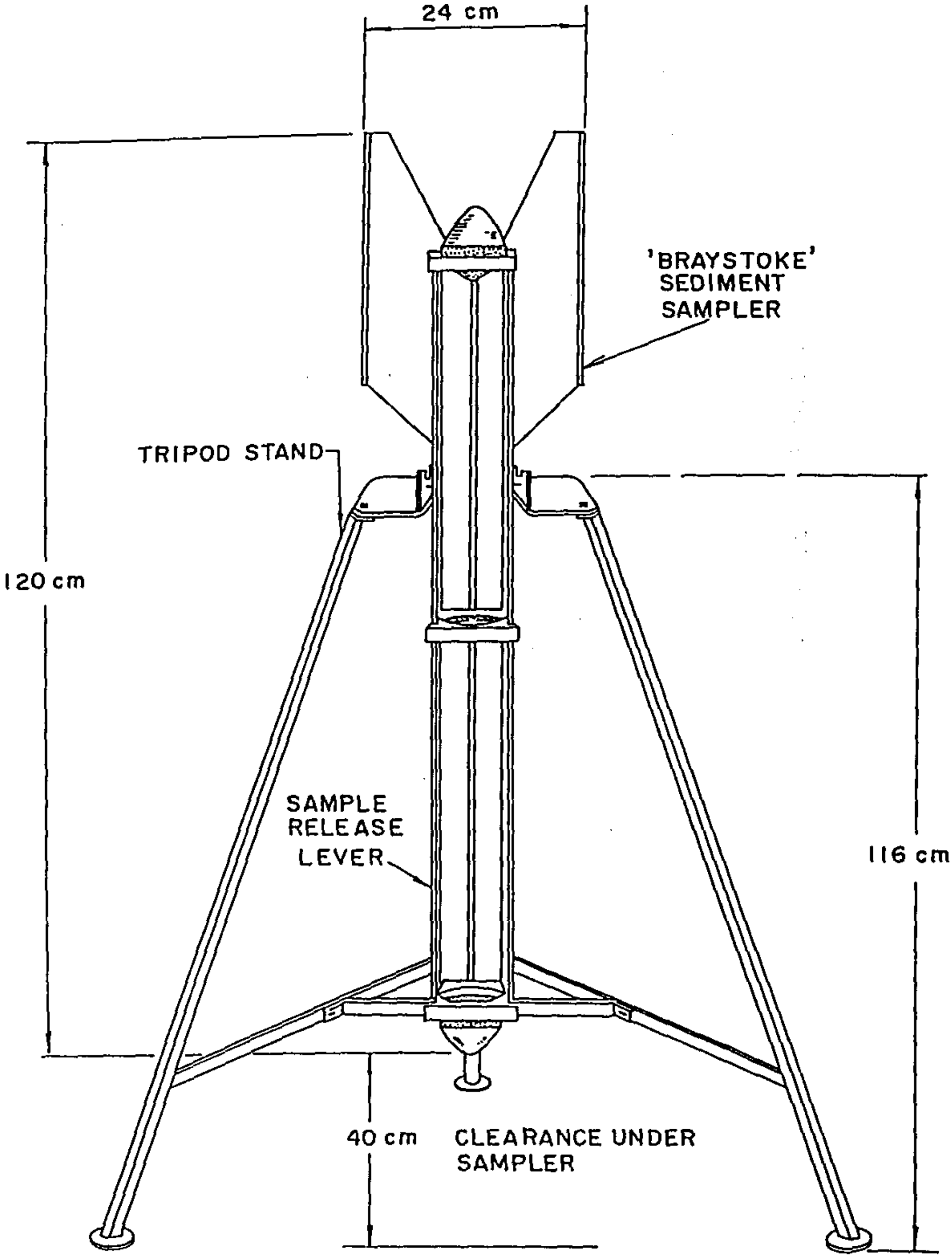

Fig. 15 Owen Tube Type In-Situ Settling Velocity Equipment (on boat)

2.3 Topographical data

The most fundamental problem related to siltation is to discover from where sand and silt are carried and deposited in navigation channels or in ports and harbor areas. As long as this original source is not removed, it is impossible to change topographical tendencies which have continued over a long period of time. Therefore, it is important to observe topographical changes over a long period of time in the order of several decades or even several centuries. This data will be very useful when planning future ports or harbors.

It can also be concluded that there are some cases in which no adequate measures can be taken to prevent siltation if the surrounding area is experiencing depositions.

Fig. 16 shows the advance of the coastline in Kumamoto over a long period from the 1500s to the present[6]. This record shows the advance of the coastline under positive efforts to reclaim the surrounding land area. However, reclamation projects are only made possible thanks to the advance of the coastline due to the long-term sedimentation of sand and/or silt from rivers. Fig. 17 shows the advance of the estuary of the Chao Phraya River in Thailand[4]. By predicting long-term trends in topographic change, more economical projects for ports and for navigation channel maintenance can be formulated.

Long-term trends in topographic changes can be predicted on the basis of information obtained by aerial photographs or remote-sensing technology that utilizes artificial satellites. Detailed information on topographic features over a wide area can be obtained by photographic data taken from a high altitude. By comparing a photograph taken at a certain time with another taken at a different time, data on topographic changes that have occurred in the interval can be obtained two-dimensionally. Furthermore, it may prove possible to understand topographic changes over a fairly long period by analyzing data on geological distributions or a distribution of vegetation obtained from aerial photographs or satellite images taken at the present.

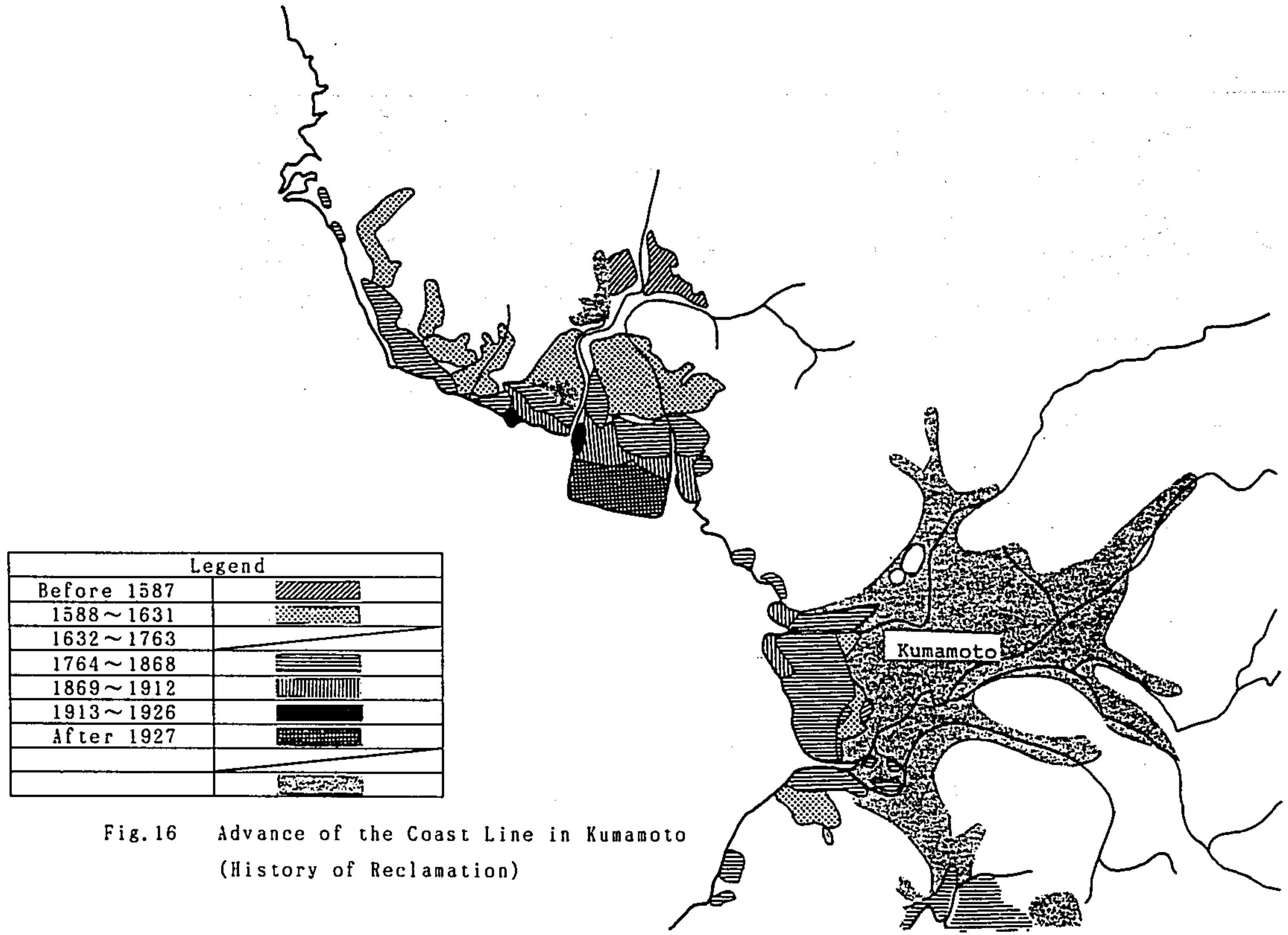

Fig.16 Advance of the Coast Line in Kumamoto
(History of Reclamation)

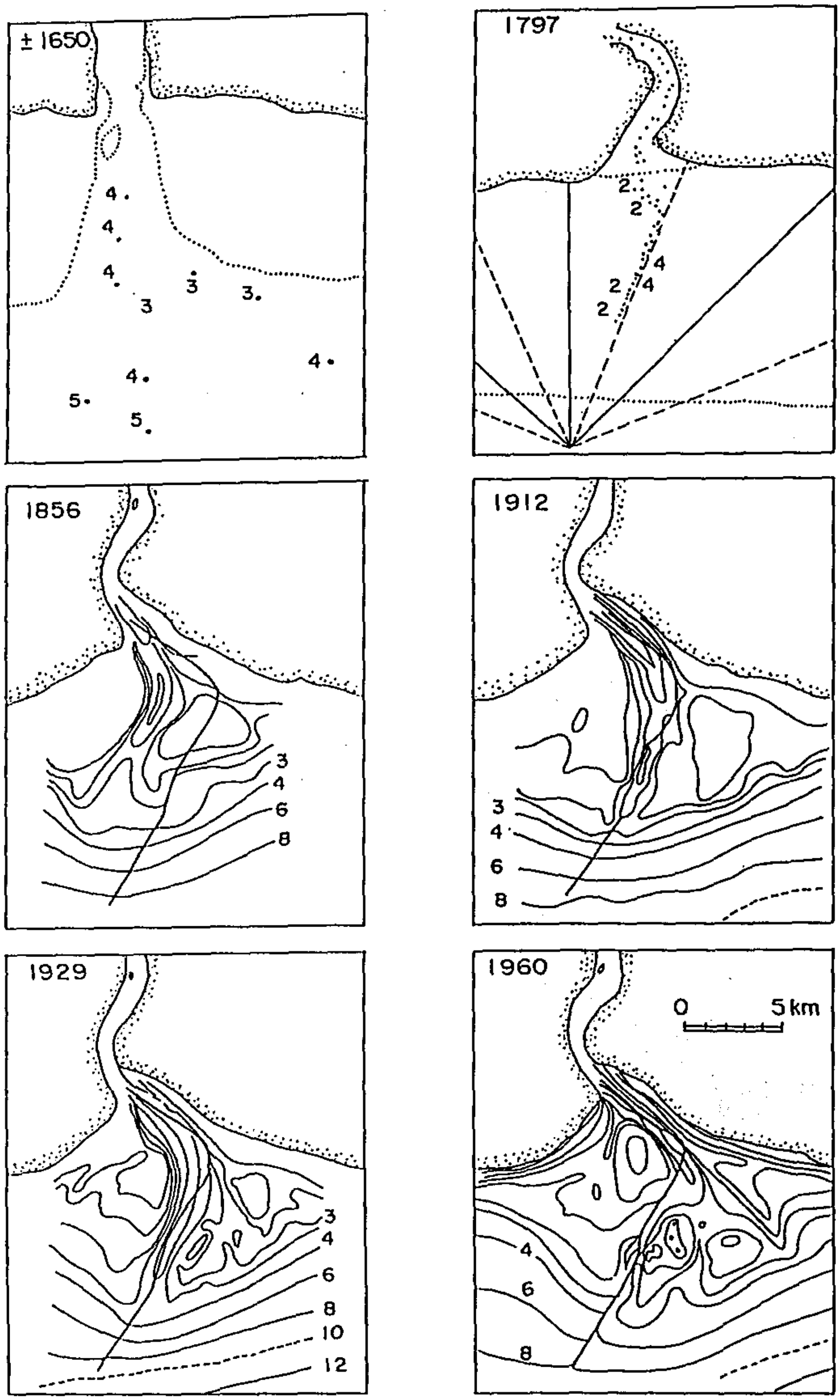

Fig. 17 Advance of the Estuary of the Chao Phraya River

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