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OBSERVATION ON SUBMERGED SAND RIPPLES WITH HEIGHTS RANGING FROM 30 TO 200 CM OCCURRING IN TIDAL CHANNELS OF S.W. NETHERLANDS

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SUMMARY

An investigation of submerged sand ripple fields with ripple heights from 30-200 cm in the fluvial tidal and tidal channels of the S.W. Netherlands was made. Such rippled surfaces were found in fluvial tidal channels, at the confluence of tidal channels and in pronounced ebb and flood channels. However, over large areas no ripple fields of this kind were observed. Ripple areas do not distinguish themselves from non-rippled areas by a difference in general current characteristics or composition of the bottom material, although no ripple (30-200 cm) fields were found in areas where the bottom material contains more than 15% mud.

The asymmetry of ripples with heights of 30-100 cm is sometimes determined by the prevailing tidal current especially in ebb and flood channels; change of the asymmetry with the turn of the tide does occur. The asymmetry of ripples with heights from 100-200 cm showed much more constancy. It mostly did not change with the turn of the tide.

The dimensions of the ripples in the fields may change rather rapidly. There is no relation between ripple height and water depth. It was observed that the orientation of the ripple crests is influenced by the spiral flow in tidal channels.

INTRODUCTION

The engineering works in the SW parts of The Netherlands call for experiments by means of large hydraulic models and tidal computations. Evaluation of the bottom roughness is very important in this respect. Therefore the description of the ripple fields in these areas may contribute to the evaluation of the bottom roughness to be applied in model and computation.

Furthermore bottom ripples in tidal waters may indicate the direction of predominant sand transport near the bottom and the variation of this direction in cross sections of the channels.

For the above mentioned reasons this descriptive and empirical investigation was set up. It is hoped that it may contribute to a better understanding of the influence of some relevant factors on the form and presence of the ripples in question in a tidal area. Ripple fields on intertidal shoals are not treated in this paper. As regards the different terms used in this paper the reader is referred to the glossary at the end of this paper.

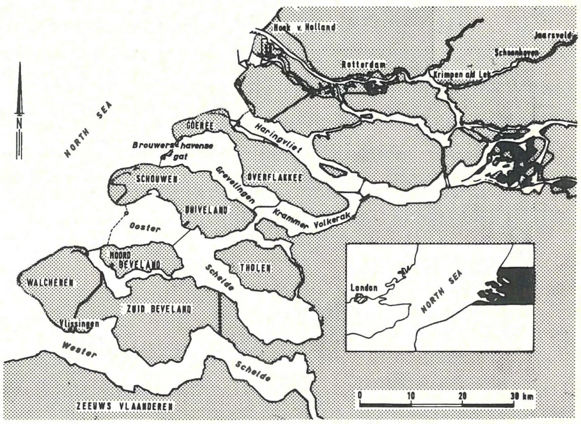

Fig. 1
Investigated area.

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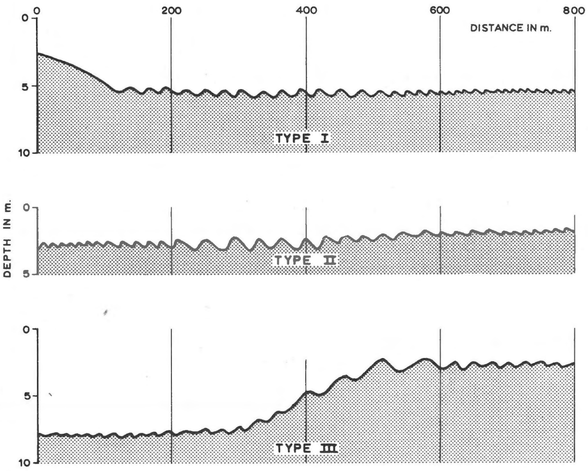

Fig. 2
Types of ripple fields (schematised after echo sounding profiles).

METHOD OF INVESTIGATION

All channels in the investigated area were sounded at least two times. The inaccuracy of the depth soundings is about 0,2 m. Wind and ship waves may augment this inaccuracy. Therefore only registrations made during calm weather were used and ripples with heights smaller than 0,3 m were excluded.

Ebb and flood directions and general information about the velocities were deduced from tidal computation. Only these echo soundings tracks were used of which the direction of the currents near the bottom was certain. So registrations made during slack water periods were not taken into account.

The water depth below MSL during the echo sounding was deduced from tide curves available from many stations in the area. The maximum inaccuracy included that of the echo sounder appeared to be 0,3 m. From some selected ripple fields, sounded during very calm weather the ripple height, ripple length and ripple index was determined.

RESULTS

Location and general properties of ripple fields in tidal channels

Ripples with heights ranging from 30-200 cm are encountered in fluvial tidal channels, in areas where tidal channels are confluent and in pronounced ebb and flood channels (as was already mentioned by v a n S t r a a t e n, 1953).

It should be noted that over large areas of the bottom of fluvial tidal and tidal channels no ripples with height ranging from 30-200 cm have been found even after repeated soundings.

Three types of ripple fields may be distinguished (figure 2).

Type 1. Ripple height and length in the field gradually increases downcurrent. The ripple field ends very abruptly and changes into a flat bottom. This type was only observed in fluvial tidal channels.

Type 2. Ripple height and length increases from the sides to the centre of the

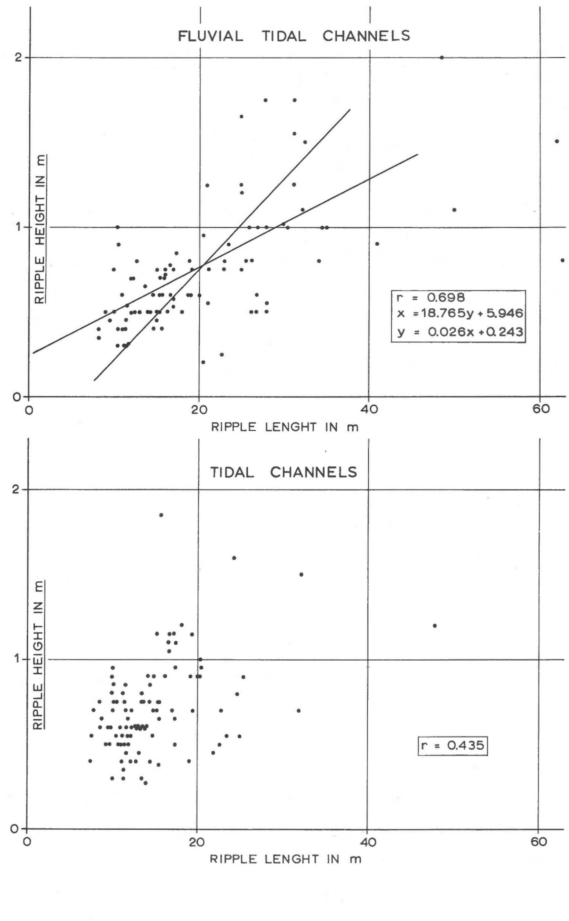

Fig. 3
Relation of ripple height (x) and ripple length (y) in fluvial tidal and tidal channels (r = correlation coëfficient).

field. This type is a common feature in tidal channels.

Type 3. At a relatively steep bottom slope (as at a shoal) the ripple height and length increases with decreasing waterdepth but at the top of the shoal the ripple height diminish very markedly. This type is generally found at the upper end of ebb and flood channels.

In all types there is a gradual increase in ripple heights and lengths from the sides to the centre of the fields. The ultimate growth of the ripples may be limited as described below.

There are some indications (see below) that at certain not well defined conditions the ripple pattern in tidal channels can be, sometimes totally, flattened. It is possible that the frequency of occurrence of such conditions is such that ripples with heights above a certain maximum value can not develop. The maximum observed ripple height in the whole investigated area amounted to 2,5 m.

The variability of the ripple fields in time was studied by repeated sounding of the same tracks with time intervals of 1 to 4 days. It appeared especially in the indifferent channels that very rapid variations in the ripple fields may occur. The maximum reduction in mean ripple height in a field was 1 m within one day, but reductions of 0,5 m in one day were fairly common. The variations in the ripple fields in ebb and flood channels were considerably smaller than in the indifferent channels. Reduction of ripple height of 0,5 m within 3 days and more were observed.

No relationship could be established between the variations in the ripple fields and variation in the river discharge or tidal characteristics (spring – neap tide, wind influences on tide curves etc.). It may be noted that in the ripple fields a reduction of the ripple heights, even below the 0,3 m inaccuracy level, usually is followed by a sometimes rapid rebuilding. This is in contrast to other areas of channels in which even after repeated sounding never ripples higher than 0,3 m were observed. There seem to be some – still obscure – hydraulic conditions which favor the formation of large ripples in some areas and prevent it in other areas. A comparison between mean current velocity data from both types of areas does not show remarkable differences.

We thought formerly that the properties of bottom material in areas of ripples (30-200 cm) differ from those in areas which are devoid of such ripples. However, from the many grainsize data of bottom samples of both kind of areas it became evident, that the median grainsizes (d_{50}) does not show a significant difference. There was also no definite relation between the ripple height and the mean of the d_{50}-values of samples from (30-200 cm) ripple fields.

As to the mud content (is percentage material with diameter $< 50\ \mu$ in total sample) no ripples (30-200 cm) were observed in areas where the bottom contains more than 15% mud.

Asymmetry of ripples (30-200 cm)

It is generally accepted, that in rivers the direction of propagation of the ripples may be deduced from their asymmetry. In tidal channels, however, with bidirectional sediment transport an incidentally observed ripple asymmetry may point to the direction of the ripple movement at that time but needs not to be necessarily a measure of the resultant travelling direction of the ripple.

We may formulate the following alternatives:

1. If the ripple form (irrespective of the height) would adapt itself rapidly to the current direction then ebb ripple fields should prevail during ebb current action and flood ripple fields during flood current action.
2. If the ripple form adapts itself more slowly to the change of the current direction than there should be a considerable amount of fields with flood ripple morphology left after the ebb periods and conversely. This would hold true especially for the higher ripples because the sand movement, necessary for an observable change in ripple form is greater for higher ripples than for smaller ones.

It is clear that the outcome will largely depend on the hydraulic character of the channels involved, which may be ebb, flood or indifferent channels. In these channels the currents in one direction may dominate to such an extent that the counter current can only slightly remodel the existing ripples but does not cause a shift in the ripple asymmetry.

To test the above mentioned assumptions 923 ripple fields all over the area were analysed. The results are given in table 1. To make the interpretation of the data independent of the number of observations the total number of ebb ripple fields, flood ripple fields and symmetric ripple fields were each taken as 100%. It should be noted that the

TABLE 1

Ripple fields classed according to ebb or flood tide, asymmetry and channel characteristics.

		Ripple Height m	Ebb	Fl.	Indiff.	Ebb	Fl.	Indiff.	Ebb	Fl.	Indiff.	Ebb	Fl.	Indiff.
			Channel character											
			Numbers			Totals			Percentages			Totals		
During ebb	Ebb ripples	0.3-0.49	37	5	30				9.9	1.3	8.0			
		0.5-0.99	71	14	31	149	24	71	19.0	3.7	8.3	39.9	6.4	19.0
		1.0-1.49	34	4	10				9.1	1.1	2.7			
		< 1.50	7	1	–				1.9	0.3	–			
	Sym. ripples	0.3-0.49	44	17	42				15.0	5.8	14.3			
		0.5-0.99	20	2	10	73	21	54	6.8	0.7	3.4	24.8	7.2	17.7
		1.0-1.49	8	2	2				2.7	0.7				
		< 1.50	1	–	–	–	–	–	0.3	–	–			
	Flood ripples	0.3-0.49	5	5	12				2.0	2.0	4.7			
		0.5-0.99	10	29	16	18	64	34	3.9	11.3	6.3	7.1	25.0	13.3
		1.0-1.49	2	22	6				0.8	8.6	2.3			
		< 1.50	1	8	–				0.4	3.1	–			
During flood	Ebb ripples	0.3-0.49	25	2	32				6.7	0.5	8.6			
		0.5-0.99	11	5	38	37	9	84	2.9	1.3	10.2	9.9	2.3	22.6
		1.0-1.49	1	2	10				0.3	0.5	2.7			
		< 1.50	–	–	4				–	–	1.1			
	Sym. ripples	0.3-0.49	21	26	54				7.2	8.9	18.4			
		0.5-0.99	2	18	18	23	48	74	0.7	6.1	6.1	7.9	16.4	25.2
		1.0-1.49	–	4	2				–	1.4	0.7			
		< 1.50	–	–	–				–	–	–			
	Flood ripples	0.3-0.49	1	20	9				0.4	7.8	3.5			
		0.5-0.99	1	44	19	3	99	38	0.4	17.2	7.4	1.2	38.7	14.8
		1.0-1.49	1	21	9				0.4	8.2	3.5			
		< 1.50	–	14	1				–	5.5	0.4			
		Totals	303	265	355							90.8	96.0	113.3

determination of the ebb or flood current as defined in the glossary 2 is subject to substantial error, especially when small current velocities occur. However, it was hoped that from the bulk of observations a general tendency could be established. From the data compiled in table 1 it may be seen that the alternative 2 prevails over alternative 1. The asymmetry of the ripples (30-100 cm) may change with the turn of the tidal currents, but this is not always the case. The asymmetry of the ripples (100-200 cm) most times does not change with the turn of the tides. Furthermore the higher the ripples the more the asymmetry is determined by the hydraulic character of the channel. Finally flood ripple fields have mostly higher ripples than ebb ripple fields.

Influence of current velocities near the bottom on the asymmetry of ripples

Current velocity data are used to verify the fact that the hydraulic character of the channel influences in an obvious way the asymmetry of the ripples. From 22 ripple fields current velocity and vectorial data gathered over a full tidal cycle were available. From these data are determined the mean ebb and flood current velocity in the vertical ($\overline{v}$), the maximum ebb and flood current velocity in the lowest 1/10 of the waterdepth ($v_{max\ 1/10}$) and the time in minutes in which the velocity reached a value of 75-100% of the maximum velocity in the lowest 1/10 of the waterdepth ($t_{v\,max\ 1/10}$). All measurements

TABLE 2

Ripple heights and current velocity data in some tidal channels

Inlet	Channel	Asymmetry pointing to	Ripple height m				Mean current velocity in the vertical (measured) m/sec $\overline{v}$		Maximum current velocity in lowermost 1/10 of vertical in m/sec v_{max} 1/10			Duration of current velocity higher than 75% of the maximum velocity in the lowermost 1/10 of the vertical in minutes		
			0,3-0,5	0,5-1,0	1,0-1,5	<1,5	flood	ebb	flood	ebb	difference	flood	ebb	difference
Volkerak		flood		x	x		0,6	0,6	1,28	0,62	0,66	95	130	35
Haringvliet	Slijkgat	flood	x	x			0,6	0,55	0,89	0,42	0,47	81	207	126
	Slijkgat	flood	x	x			0,5	0,6	0,77	0,49	0,28	60	150	90
	Bergse Maas	flood		x	x		0,5	0,4	0,74	0,57	0,17	72	135	63
Krammer	Noordergat	flood		x	x	x	0,6	0,5	0,65	0,40	0,25	100	38	62
Grevelingen	Bocht van St.Jacob	flood	x	x			0,5	0,5	0,88	0,58	0,30	12	106	94
Brouwershavense Gat	Springerdiep Z	flood		x			0,4	0,5	0,78	0,56	0,22	68	194	126
Brouwershavense Gat		flood		x			0,5	0,5	0,60	0,45	0,15	110	92	18
Zijpe		ebb		x	x	x	0,8	0,8	1,00	1,08	0,08	129	108	21
Oosterschelde	Westgat	ebb	x		x		0,50	0,65	0,61	0,94	0,33	156	87	69
	Roompot ebgeul	ebb	x				0,35	0,70	0,64	0,80	0,16	76	88	12
Krammer		sym.	x				0,6	0,7	0,87	0,82	0,05	116	114	2
Oosterschelde	Schaar van Kolijn	sym.			x		0,8	0,75	1,10	0,90	0,20	93	170	77
	Roompot	sym.				x	0,7	0,8	1,28	0,92	0,36	40	88	48
	Geul	sym.				x	0,5	0,3	0,88	0,34	0,54	36	76	40
	Westgat		x	x			0,35	0,4	1,18	0,9	0,28	108	–	
Haringvliet		ebb	x	x					0,84	0,94	0,10	77	115	38
Krammer	Zuid Vlije	ebb	x	x	x		0,4	0,6	0,30	0,90	0,60	68	38	30
Grevelingen	Bocht van St.Jacob	ebb	x	x			0,2	0,6	0,25	0,82	0,57	56	62	6
Grevelingen		ebb		x	x		0,4	0,5	0,41	0,54	0,15	84	122	38
Brouwershavense Gat		ebb		x			0,4	0,7	0,56	0,92	0,36	84	46	38
Oosterschelde	Roompot	ebb	x	x			0,4	0,7	0,52	0,82	0,30	45	183	138
	Roompot	ebb	x				0,4	0,65	0,65	0,76	0,11	48	160	112
	Hammen	ebb	x				0,5	0,8	0,98	1,18	0,20	78	186	108

For location of these channels see hydrographic maps.

TABLE 3

Variation of the maximum current velocity in the lowermost 1/10 of the vertical measured in four tidal channels.

Channel	Date	Maximum velocity in lowermost 1/10 of vertical m/sec	
		Ebb $V_{max\ 1/10}$	Flood $V_{max\ 1/10}$
Volkerak	29- 1-1965	0.60	0.80
	8- 2-1965	0.50	0.80
	15- 2-1965	0.80	0.50
	25- 2-1965	0.79	0.55
Haringvliet	12- 5-1960	0.95	1.20
(Deltageul)	17- 5-1960	0.90	0.90
	16- 2-1961		1.80
Haringvliet	18-10-1960		0.90
(Rak van Scheelhoek)	19-10-1960		1.00
	17- 1-1961		1.50
	24- 1-1961	1.00	
	23- 2-1961	0.80	
Haringvliet	16- 9-1959		1.00
(Slijkgat)	10- 5-1960		1.50
	11- 5-1960		1.55
	13- 5-1960	0.95	
	18- 5-1960	0.70	
	19- 5-1960	0.45	1.20

were reduced to mean tidal conditions (Table 2). Waterdepth in ripples areas was determined at the crests of the ripples.

It appeared that $\overline{v}$ and $t_{v\,max\ 1/10}$ did not have a significant influence on the asymmetry and on the ripple heights.

However, it could be concluded that if the differences between ($v_{max\ 1/10}$ ebb) and ($v_{max\ 1/10}$ flood) exceeds 0,10 m/sec the ripples are asymmetric. The travelling direction is then determined by the flow direction with the highest value of $v_{max\ 1/10}$. Is ($v_{max\ 1/10}$ flood) larger than ($v_{max\ 1/10}$ ebb) flood ripples are found in the ripple field. This also indicate that a rapid shift of the ripple asymmetry after the turn of the tide is not likely as stated in the preceding section. The asymmetry of the ripples in the channels is conservative and determined by the prevalent tidal current.

It was stated above, that the occurrence and the asymmetry of ripples (30-200 cm) show variations in the course of time. In order to get more information about this the variability in time of $v_{max\ 1/10}$, current data were analysed from 4 measurements points where at least 3 times velocity readings were made (Table 3).

It came out that the value of $v_{max\ 1/10}$ may change in time with a factor 1,2-2,0. Near the bottom rapid variations in the $v_{max\ 1/10}$ values may occur in short time. Also the difference between $v_{max\ 1/10}$ during ebb and flood appeared to change considerably in time and may even pass from a flood into an ebb predominance and vice versa. This may be one of the reasons of the rapid changes in the ripple patterns in the investigated tidal waters.

Properties of (30-200 cm) ripple fields

From 70 selected ripple fields in tidal channels and 103 ripple fields in fluvial tidal channels of the Lower Rhine mean ripple parameters of the fields were determined including ripple height (h) ripple length (1) and ripple index (1/h).

Figure 3 shows that the correlation between ripple heights and ripple length in fluvial tidal and tidal

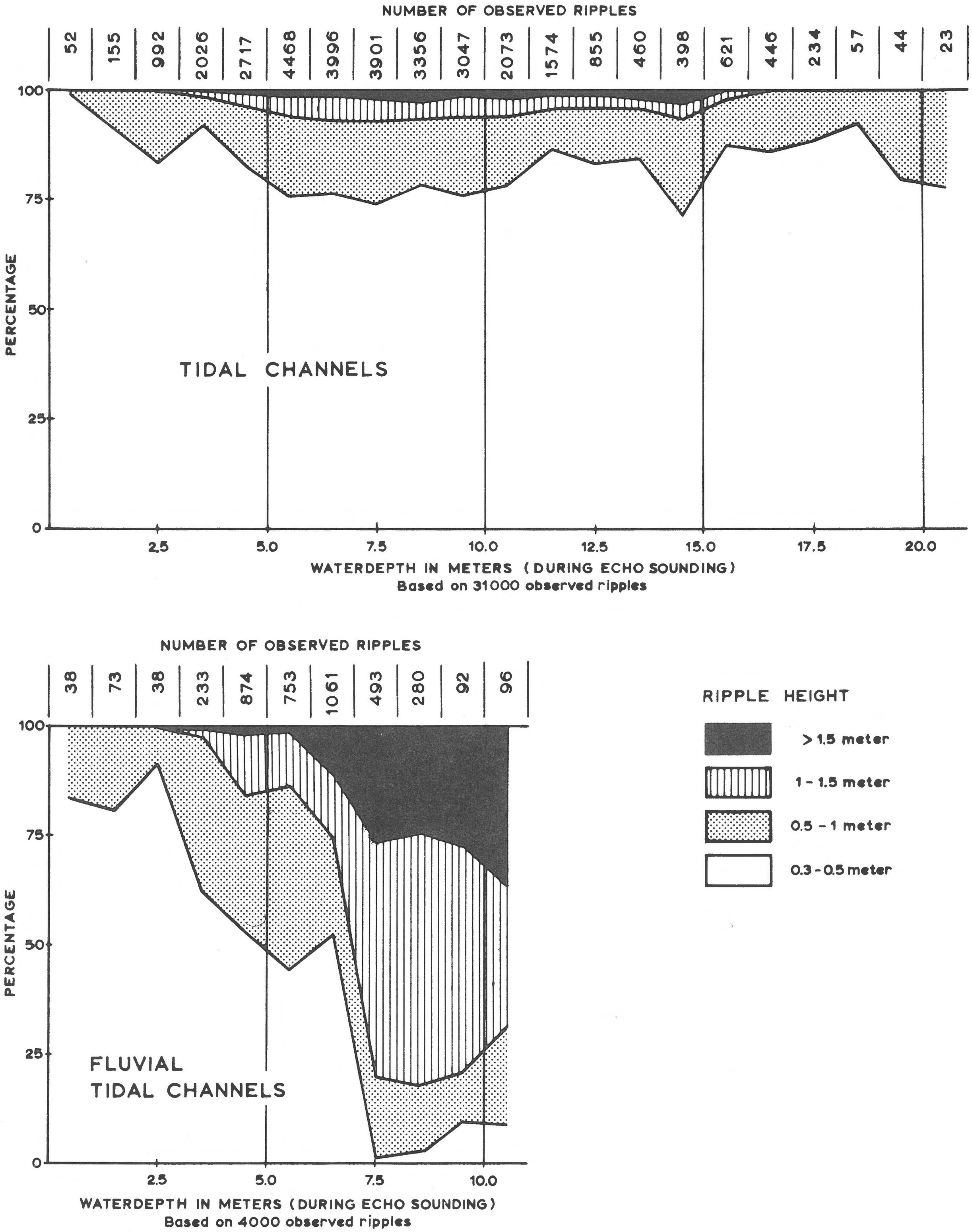

Fig. 4
Percentage of ripples of different height intervals in relation to water depth.

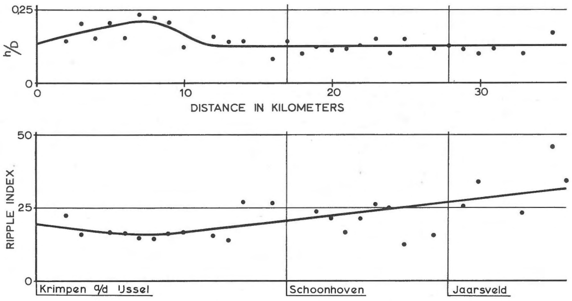

Fig. 5
Variation of ripple characteristics along the axis of the fluvial tidal channel of the Lower Rhine.

channels is poor. The same holds for the ripple heights (h) and waterdepth (D) (figure 4). If in the fluvial tidal channel only the data in the channel axis are considered than it appears (figure 5) that the ratio h/D is fairly constant, varying between 1/6 and 1/10. This agrees with the mean ratio h/D = 1/6, found by Y a l i n (1964) from many flume and field data.

Alignement of ripple crests

In some channels the orientation of the ripple (30-200) crests could be determined by means of transit sonar tracks (figure 6). It is assumed that the travelling direction of the ripples is normal to the ripple crests and in accordance with their asymmetry. It appeared from the sonar registrations that in some channels the travelling direction of the ripples makes an angle with the channel axis. This holds true in straight as well as in bending channels. As a travelling direction of ripples represents the general direction of sediment displacement the above means that in some parts of the channels the direction of sediment movement near the bottom is angular to the channel axis. This implies of course that the dominant direction of the currents near the bottom makes a similar angle with the channel axis. A possible explanation of this phenomenon is the presence of secundary currents in these channels causing a helicoidal flow. Helicoidal flow is generated by the combined effect of longitudinal and transversal gradients of the water surface. A good treatment of the subject is given by R o z o v s k i i (1961) and in the NEDECO report (1959, p. 525-533). The transversal gradients in a tidal area may be caused by centripetal forces acting on the water particles moving in a channel bend and/or by the Coriolis force. The direction of the sediment movement near the bottom is governed by the resultant vector of the forces acting on sediment particles on the bottom. Fig. 7 illustrates this for the case of a bending channel. If we take the x-axis parallel and the y-axis normal to the channel axis then due to the longitudinal and transversal gradients of the water surface there is a flow which exercises a tractive force F_x and F_y, respectively on the sediment particles on the bottom. There also act gravity forces G_x and G_y as a result of the bottom slope. From figure 7 it is clear that the angle between the resultant force vector and the channel axis depends to a large extent on the magnitude of F_y.

According to v a n B e n d e g o m (1947):

$$F_y/F_x = 1{,}6\, U_y/U_x = \frac{0{,}04\, v^2}{g r i_x} \qquad (1)$$

(Where U_x and U_y are the surface velocities in x and y direction, v is the mean velocity over the vertical in x direction, g is the acceleration of gravity, r is the radius of the bend and i_x is the longitudinal gradient of the water surface).

From numerous current measurements in the investigated area, analysed for U_x and U_y, it became apparant that U_y/U_x ranges between 1/3 and 1/10 for values of U_x above the critical value for sand transport. So F_y/F_x ranges between 1/2 à 1/6. According to NEDECO (1959):

$$F_x = 1/4\pi\, d^2\, \rho_w\, g a i_x \qquad (2)$$

$$G_x = 1/6\pi\, d^3\, (\rho_s - \rho_w)\ g \sin\beta_x \qquad (3)$$

$$G_y = 1/6\pi\, d^3\, (\rho_s - \rho_w)\ g \sin\beta_y \qquad (4)$$

So the ratio between F_x and G_x may be expressed as

$$\frac{F_x}{G_x} = \frac{\rho_w\, g a i_x\ 1/4\,\pi\, d^2}{(\rho_s - \rho_w)\ \sin\beta_x\ 1/6\,\pi\, d^3} \qquad (5)$$

in which: a is the waterdepth, β_x = the bottomslope, ρ_w = density of water, ρ_s = density of sediment and d is the grain diameter. If we try to evaluate the higher values of this ratio we may put a = 20 m, i_x = 5 cm/km, β_x = 1° and d = 250 microns. F_x/G_x = ca 200. If we take β_y = 2°: from (3) and (4) it follows that G_x/G_y = about $\frac{1}{2}$. Substituting these values into the four formulae for tg α mentioned in figure 7, it appears that the angle α varies between 10 and 30°. This order of magnitude may be checked by the following field data.

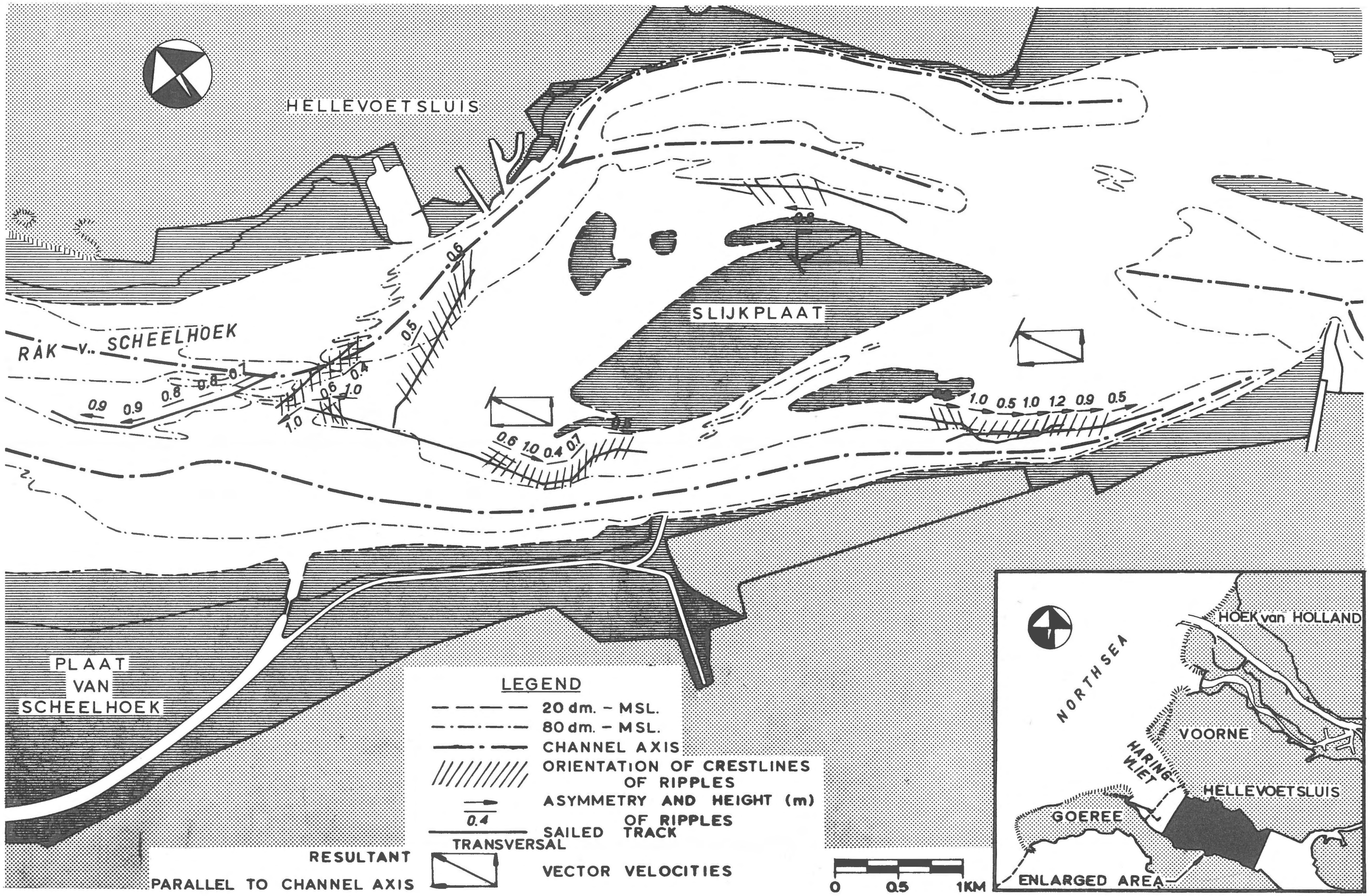

Fig. 6
Orientation of crest lines of ripples in the Haringvliet estuary, based on transit sonar registration.

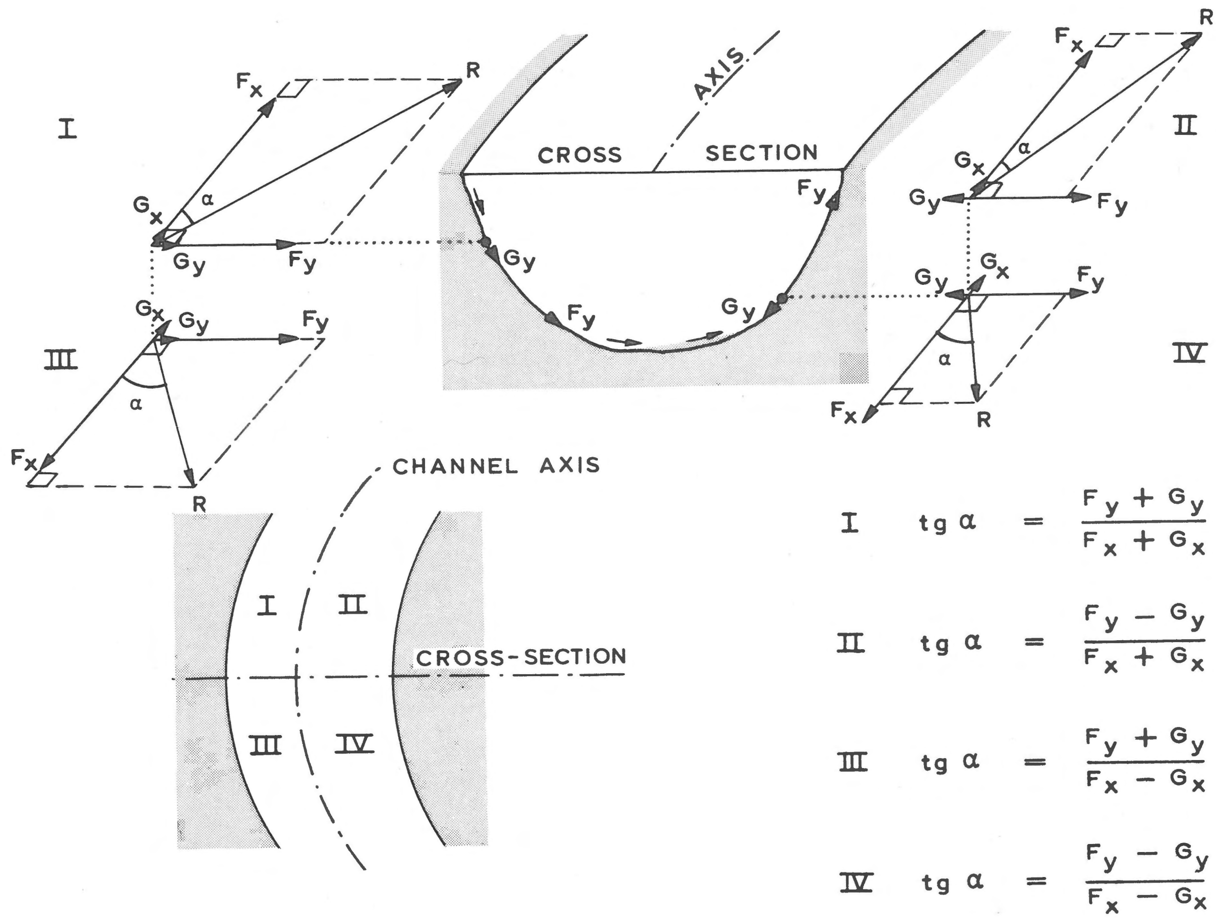

Fig. 7
Schematic representation of forces acting on sediment particles in the cross section of a bending channel. Explanation see text.

The direction of sediment movement over the bottom could be derived from foresets of macro current ripples, exposed in sections in the building pit for the Haringvliet sluices. These sections were dated

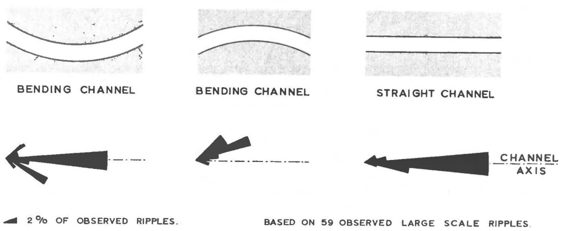

Fig. 8
Measured foreset directions of large scale ripples in sections in the building pit in the Haringvliet estuary in relation to channel type.

roughly with the help of hydrographic maps, which were available from the building pit site since 1821. This dating is not very accurate, because compaction cannot be evaluated. But the direction of the channel axis during the formation of the strata in the exposed sections can be estimated from these maps with an accuracy of 10°. Fig. 8 shows that the angle α between channel axis and direction of sediment movement may reach values up to 50°. This figure also indicates that in straight channels this angle is normally small, whereas in the bending channels the deviations are much larger, especially in the bends with the central point in the south. In the Haringvliet these bends have much shorter radia than the bends with the central point at the North.

Further informations concerning the above mentioned angle may be gained from transit sonar tracks

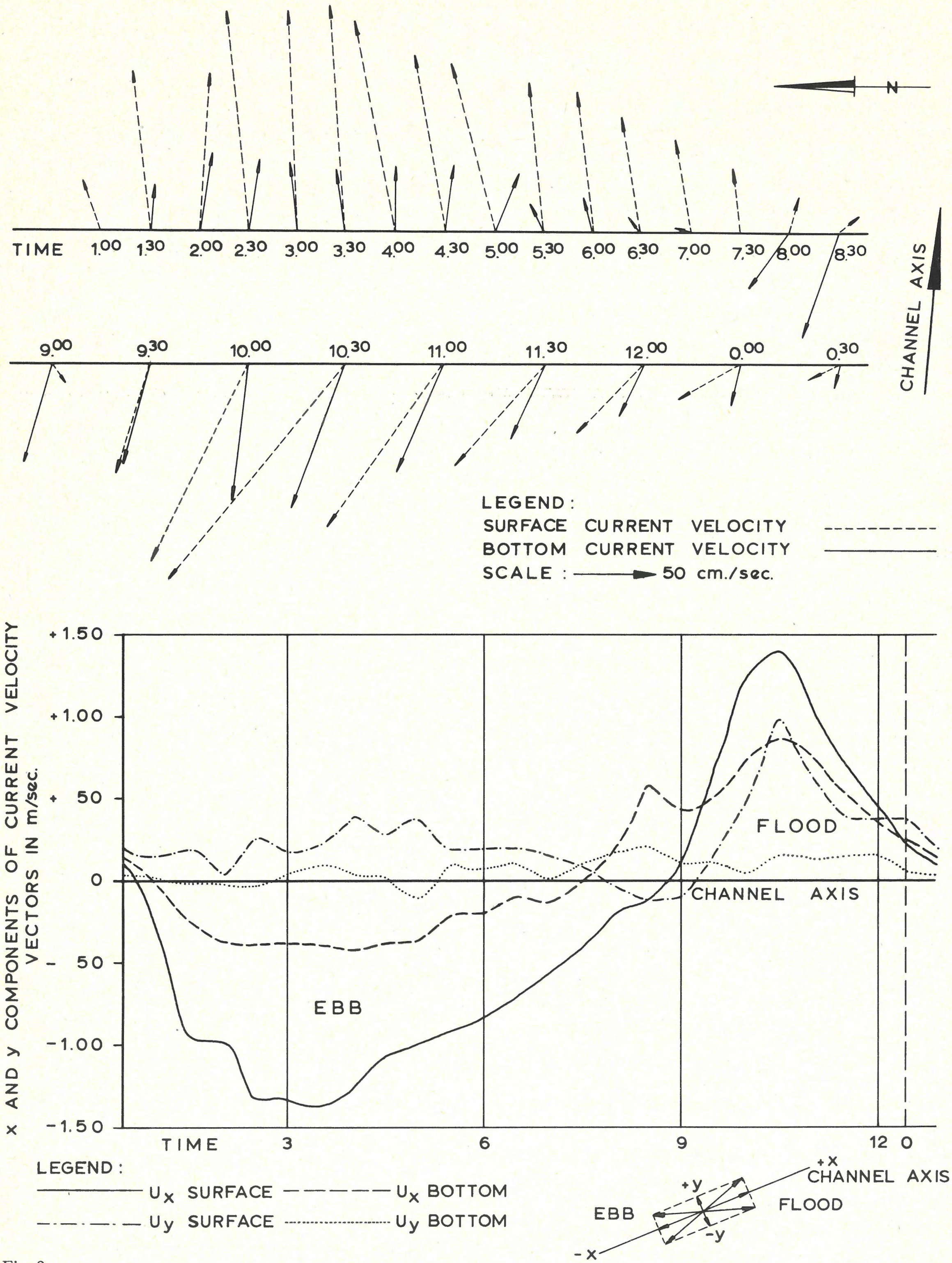

Fig. 9
Current velocity vectors, measured during one full tidal cycle in the centre of a flood channel in the mouth of the Haringvliet estuary.

(figure 6), which also indicate that the angle between channel axis and ripple crest lines can reach values up to 30° to 40°.

The direction of sediment movement may be assumed to be parallel to the currents near the bottom. From current measurement in the investigated area it appears that the current direction near the bottom (measured at a height of 0,5 above the bottom) may deviate from the channel axis up to 50°. Deviations between 0 and 20° are commonly observed. An illustrative example is given in figure 9.

Secundary currents have thus in bending tidal channels a definite bearing on the direction of sediment movement.

One more point regarding figures 6 and 7. The direction of sediment movement during one tidal current phase is not necessarily diametrically opposed to that prevailing during the counter current phase. In bending tidal channels in which the sand transport during ebb and flood tide is in the same order of magnitude cross patterns of ripples may be expected. Transit sonar registrations indeed reveal irregular wavy crest lines of ripples in such channels. However, in very pronounced ebb or flood channels, characterised by a predominant sand transport in one current direction mostly straight crested or slightly sinuous ripples were observed (fig. 9).

This indicates that not only the direction of sediment movement but also the ripple pattern and the corresponding sedimentary structures may be influenced by secundary currents in the channels.

DISCUSSION

This study was a reconnaissance of ripple fields in the tidal waters of the S.W. part of The Netherlands. It is still uncertain why in some areas there are ripples (30-200) and not in other areas. Neither the general current data nor the composition of the bottom material show marked differences in both areas. On the other hand it was observed that the magnitude of the ripples in the fields may change very rapidly. There are indications that these changes are due to variations in the bottom current velocities. It may be suggested that these variations in areas covered by (30-200) ripples are smaller than in areas where these ripples are absent.

Unfortunately at this moment there are only a few over a long period continuously registrated current data in the investigated area. But from these few data it can be seen, that considerable variations in f.i. the maximum current velocities, in successive tides do occur.

In ebb and flood channels, characterised by predominance of current velocities in one direction over the other, variation of the velocities may influence the travelling direction of the smaller (30-100 cm) ripples. If this predominance is relatively large, variations may have less influence. In this case ripples of larger dimensions may be present.

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GLOSSARY OF TERMS

Ripples (30-200): figure between brackets gives the ripple height in cm.

Ripple field: area in which the height and asymmetry of the ripples are almost the same.

Flood ripple: asymmetric ripple, steep lee side in the same direction as the flood current flows.

Ebb ripple: asymmetric ripple, steep lee side in the same direction as the ebb current flows.

Symmetric ripple: ripple which does not show a marked asymmetry.

Tidal channel: channel in which the current directions change with the tide.

Fluvial tidal channel: channel without slack water phase.

Flood channel: channel in which the flood volume exceeds the ebb volume.

Ebb channel: channel in which the ebb volume exceeds the flood volume.

Indifferent channel: ebb volume and flood volume are in the same order of magnitude.

Flood period: period between the moment that the mean flood velocities at 15 cm above the bottom are higher than about 0,3 m/sec till the moment that the following ebb velocity near the bottom become larger than 0,3 m/sec. (The asymmetry of the ripples can adapt itself to the reversed current direction after the current velocities are large enough to transport the fine to medium sand).

Ebb period: analogous definition as flood time.

Ripple height (h): vertical distance in m between ripple crest and the level of the ripple trough base.

Ripple length (l): distance in m between two successive ripple crests.

Waterdepth: depth in m between mean sea level and the mean height of the ripple crests in a ripple field.

Ripple index: ripple length devided by ripple height.