

CHAPTER 57

CURRENTS IN TIDAL FLATS DURING STORM SURGES

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Wind action in the viewpoint of coastal engineering is mainly a topic for discussions or investigations of waves, breakers, storm surges, sand transport on beaches and so on. Offshore currents, generated by wind shear stress concern more the scientific field of oceanographers.

But in shallow coastal water windinduced drift currents indeed may be important for coastal engineering problems, as sediment transport, sewage spreading, salinity and so on. For example, along the German North Sea Coast (Fig. 1) we have a rim of extended tidal flats, built up by sand and mud and covered only by a water layer of 1 to 2 m at high tide. At low tide sands and mud flats fall dry. Fig. 2, an aerial view, gives an impression of a typical tidal flat, the "Neuwerker Watt" at the south side of the Elbe Estuary. The distance between main land and the sea side border of the flat is here about 20 km. A lot of investigations have been carried out here - initiated by a harbour planning task - giving some interesting results about currents in the tidal flat area during strong winds and storm surges.

For the current measurements a recording current meter (Fig. 3) has been used, fixed at a tripod aluminum frame in 40 cm above bottom. The propeller meter starts at velocities of 5 cm/s. Tests in a flume proved that orbital currents give no disturbance if unidirectional currents of a certain magnitude are superimposed.

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Fig. 1 Tidal Flats in front of the German North Sea Coast

Fig. 2 Aerial View of the "Neuwerk" Tidal Flat



The diagram in Fig. 4 presents a typical example of one measurement of 17 days duration, including a severe storm surge (2.11.1965). Velocities are comparatively small at normal tides, in maximum 30 to 40 cm/s. Directions are adverse in flood and ebb tide. Towards the end of the observation period wind increases to 8 and 9 Bft, blowing from west, that means coastwards. Water level raises and a storm surge occurs on 2. November. The currents increase with wind speed and exceed about 1 m/s in the storm surge. Current directions obviously are influenced - the adverse ebb and flood current is substituted by a more unidirectional movement towards northeast, that means in the direction of the acting wind shear stress.

The wind influence can still better be seen at another graph (Fig. 5) of the same measurement - it is a plot in form of a vectorial track, adding the consecutive data of velocity and direction. The zero point is at tide Nr. 564. The residual flow of the first 15 tides - to Nr. 580 - is comparatively small. The wind induced water motion starts with a significant turning of the vectorial track towards north-east. The residual current velocity increases up to 20 km/tide and more in the storm tides Nr. 590 and 591.

This is a single but typical result. A lot of data of that kind have been collected, suitable for some statistical evaluations. Fig. 6 presents the data of 50 storm surges, stemming from different stations.

In the upper diagram frequency curves of maximum velocities at normal tides and storm tides are compared. At normal tides there is a peak at 30 cm/s, that is the average maximum velocity in tidal flats. The storm surge frequency curve covers the range from 40 to 120 cm/s.

In the lower diagram a frequency curve for the relationship storm tide velocities over normal tide velocities is plot-



Fig. 3
Recording Current Meter

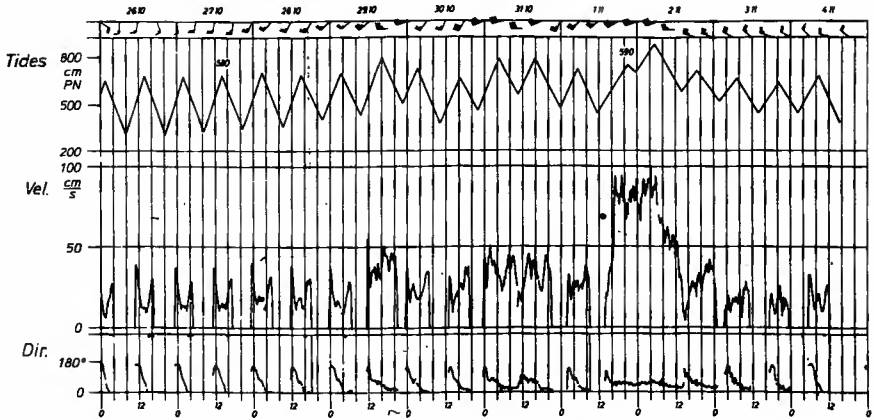


Fig. 4
Record of a Current Meter Station containing
a Storm Surge

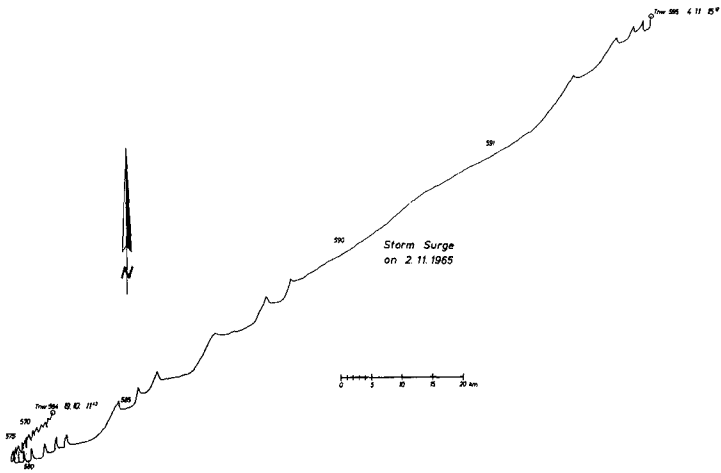


Fig. 5

Currents plotted as Vectorial Track Containing a Storm Surge (s. Fig. 4)

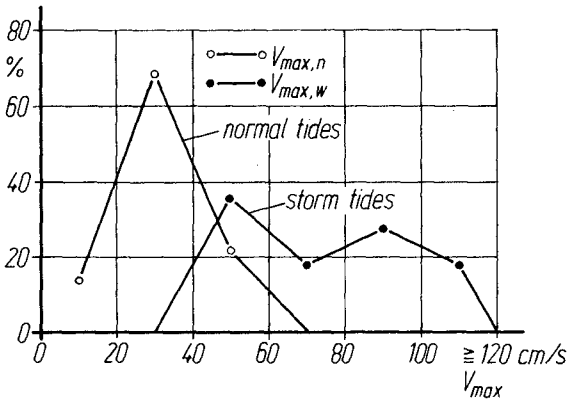


Fig. 6

Frequency of Maximum Velocities in Tidal Flats

ted. Here again a significant peak exists indicating that during storm surges the maximum velocities in tidal flats in average increase about 100%.

Fig. 7 presents curves of residual current velocities over wind speed, again evaluated from some hundred measurements at different stations. The scale in the upper plot is km/tide and the increase of residual current with wind speed - about 1 km at normal tides and about 12 km/tide at storms of 8 Bft and more - is remarkable. But this curve includes the longer duration of water cover in the tidal flat due to the raising water level. This effect is eliminated in the lower diagram with a scale of cm/s for the magnitude of the residual current. In the same range of wind velocities the residual current increases from 5 to 30 cm/s. Especially these statistical results may be helpful for example for estimations of sewage spreading under different wind conditions.

Of special interest is the dependency of current direction. Flume tests and simple mathematical models show that in a rectangular basin we have a flow in the direction of the wind shear stress in the upper layer and an adverse flow beneath that layer, the boundary being $2/3$ over bottom. The current meter used in the field program measures 40 cm above bottom, so that the records present mainly the bottom layer. There is no motion adverse to wind direction in the tidal flats in this layer. This was already shown in Fig. 4 and 5 and is proven by the Fig. 8, presenting residual currents from a simultaneous measurement at 5 different stations over 17 days plotted as vectorial tracks. At the beginning - tides Nr. 600 to 610 - there is no wind stronger than 4 Bft. This part of the track presents normal tidal currents. After that a wind period begins, the wind velocity increasing up to 10 Bft and turning from south-west over west, north-west and north to south-west again. The track of the residuals

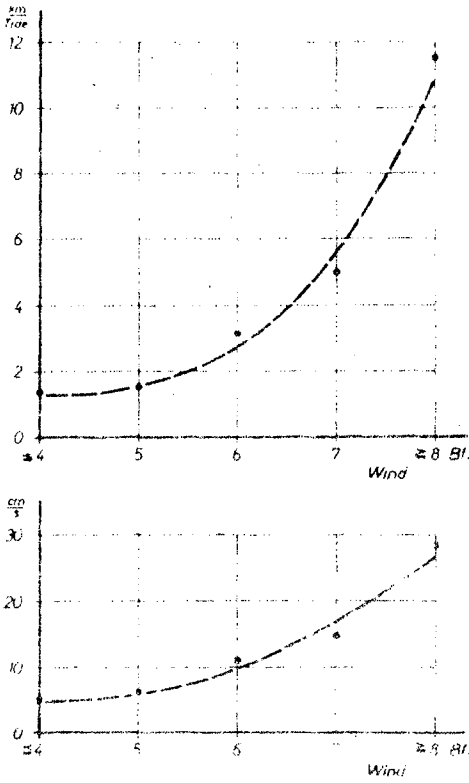


Fig. 7 Residual Current over Wind Speed

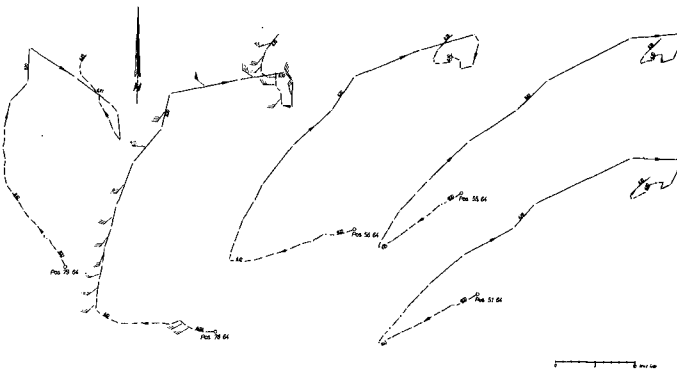


Fig. 8 Residual Currents influenced by Wind

follows that changing of wind direction. Fig. 10 gives another statistical evaluation. At one station inmidst of the Neuwerker tidal flat continuous measurements over two years have been carried out. The collected data of current directions in a 5 minute sequence were classified in groups of wind direction and wind velocity and plotted in the form of direction frequency schemes. With increasing wind velocity the normal tide direction pattern changes and currents in wind direction prevail.

It is to expect that the adverse flow in the bottom layer, which must be present to counterbalance the water transport in the upper layer in wind direction, occurs in the gullies and channels of the shallow water areas. This is proven by Fig. 11. From all measurements with considerable wind influence drift current vectors were computed by a vectorial subtraction of wind induced residual currents and normal tidal residual currents. This vector presents the pure wind influenced current under the assumption that there exist a simple superimposition of tidal and wind induced currents. This is of course a rough approximation. Then the angles between wind direction and drift current directions were computed and plotted as frequency curves. These data include measurements from the bottom layer in the channels and gullies. The left curve presents the frequency of difference angles for the tidal flat, the right curve for the channels. There is a very clear tendency that in the shallow water drift currents prevail in wind direction while in the deeper layer of the channels (superimposed to the much stronger tidal currents) a flow adverse to the wind sheer stress exists.

The question of vertical distribution of the described current pattern is of great interest, but difficult to investigate as waves prevent accurate measurements in the surface layer and tidal currents are superimposed. Flume tests and theoretical considerations show that there is a

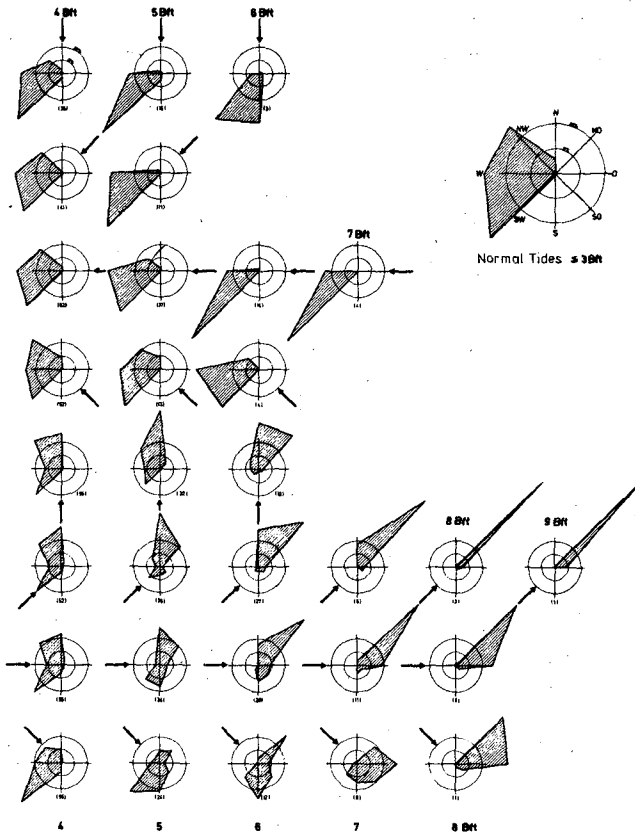


Fig. 10. Frequency Schemes of Currents at one Tidal Flat Station dependent on Wind Velocity and Direction

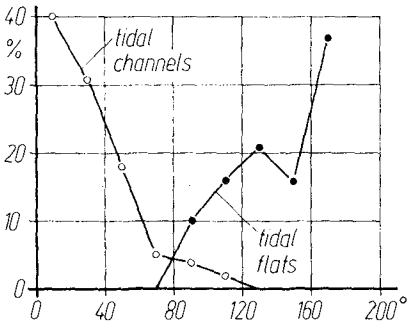


Fig. 11
Difference Angle
between Wind Di-
rection and Re-
sidual Current
Direction

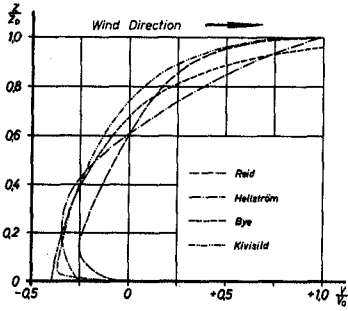


Fig. 12
tical Distribution
Velocity due to
d Shear Stress

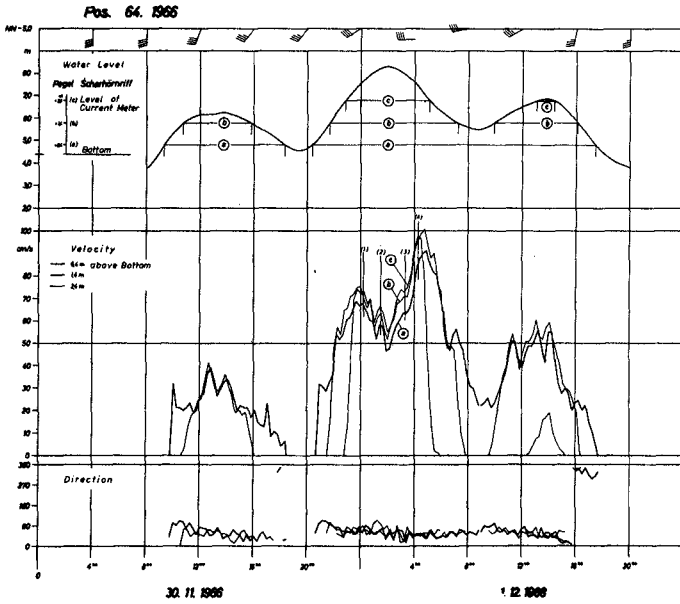


Fig. 13
Currents in 3 Levels during a Storm Surge

strong decrease of velocity in the surface layer (Fig. 12). To get some field data a special station with 3 current meters was set up in levels of 0.4, 1.4 and 2.4 m above bottom. The upper instrument was only to work at higher water levels i.e. at storm surges.

Good observations during a storm surge in December 1966 were obtained. Fig. 13 presents the most interesting part of the record. The three current meter levels a), b) and c) are marked. Neglecting some parts during raising and falling water where the upper meter may be disturbed by waves, a significant but comparatively small decrease of velocities over depth can be seen. There is no indication of a strong velocity gradient as shown in Fig. 12.

Using the data from the two lower instruments it was tried to evaluate a relationship between velocity gradient and wind speed (Fig. 14). Though there is a considerable scattering, the plot indicates that the velocity gradient decreases with increasing wind velocity up to a wind speed of 10 m/s. From this point the gradient increases with further increasing wind velocity. This result can be explained as follows: At calm weather currents at that measuring point are very small - 10 to 20 cm in average. This is a more laminar motion which indeed should have a higher gradient. Increasing wind speed leads to waves and higher turbulence with the effect of a decreasing gradient. But from a certain point - here at a wind velocity of 10 m/s - the gradient increase due to the laws of wind generated flow becomes predominant.

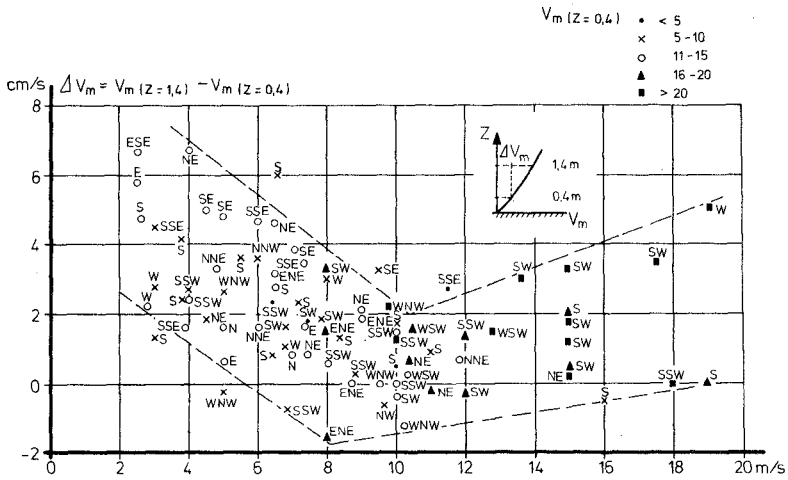


Fig. 14
Velocity Gradient over Wind Velocity

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