PASSIVE SEDIMENT MANAGEMENT: THE CURRENT DEFLECTING WALL

by R Kirby

Pressures on port operators to reduce fixed operating costs have steadily escalated over recent decades. In many ports one of the biggest fixed operating costs is dredging to maintain depths at berths and in approach channels. Most commonly the material causing the problem is cohesive fine sediment. The costs of addressing mud problems have sprialled in recent times.

Amongst the reasons for this are the ability of muds to take up dissolved and particulate contaminants which, around and downstream of industrial and intensively farmed areas, has led to harbour muds being polluted.

A second issue has been the appreciation that conventional dredging, especially hydraulic dredging, entrains large quantities of anaerobic bed deposits. Entrainment leads to a range of water quality problems, in particular to dissolved oxygen depletion and desorption of contaminants.

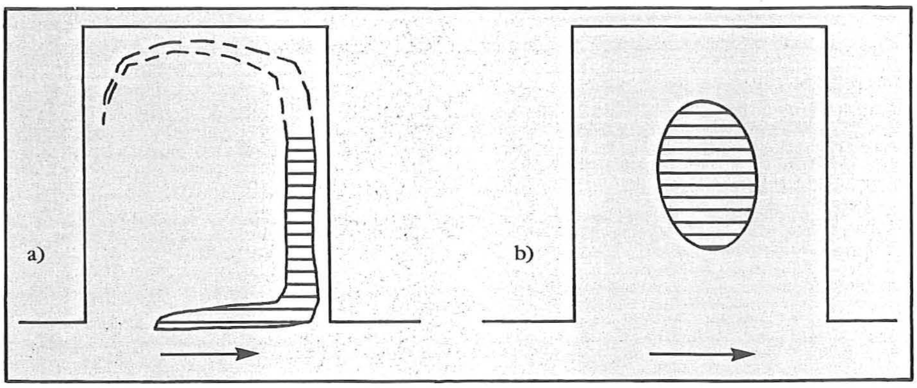

Figure 1: coarse (a) and fine (b) sediment deposition patterns in basin entrances due to eddy-induced shoaling. Röhr 1934.

Thirdly, pressure is escalating to neither dispose of dredge material ashore nor at sea, arising from a range of perceived detrimental environmental impacts.

The dredging industry has responded to these challenges in a number of ways. Amongst the most effective ways of significantly reducing dredging costs, in those limited sites where it is applicable, is the use of agitation dredging systems of a wide range of types. These rely on disturbing the bed and then permitting combinations of favourable currents and bed slopes to transport the material out of the area.

Although agitation dredging can be both effective in reducing depths and at the same time reducing costs, there is at times and in places an environmental disbenefit at the dredging site. Some techniques enhance pollutant desorption as well as increasing the dissolved oxygen demand even beyond that of conventional hydraulic dredgers.

Harbour authorities are rarely responsible in a primary sense for pollution but inherit the problems caused by others arising from the unavoidable need to dredge. The best approach is to undertake no more dredging than is absolutely necessary.

Permanent reductions in dredging need have been achieved via a number of routes. In respect of mud dredging of fairways, major reductions have been accomplished where the target depth can be set at the natural equilibrium depth of a channel.

However, in many modern ports operating depths exceed the equilibrium depth and in those channels plagued by lowly consolidated deposits of transitional character between water and the bed (often called fluid mud), increases in depth and a reduction in dredging need have been achieved by adoption of the Nautical Depth concept.

The problem of depth definition in such deposits only arose in the 1930s with the development of echo sounding apparatus, but technology to overcome the problem and the appreciation for its necessity did not arise until the 1970s.

The approach involves nominating a level within the transitional zone having shear strength or density characteristics relevant to the resistance characteristics of ships' hulls, dredger dragheads, etc. (Kirby & Parker 1974; Kirby, Parker & van Oostrum 1980). Available draft increases of 2.0m or more have been accomplished, accompanied by dredging cost reduction.

A completely different approach to another frequently-occurring siltation problem has now emerged and is the subject of this paper.

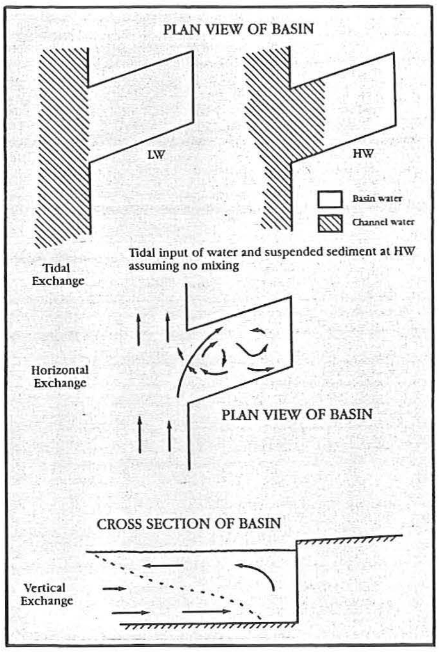

Figure 2: sketches showing the three mechanisms by which sediment enters a blind-ending tidal basin.

This is the question of shoaling under stable eddy-systems, which is evident most commonly at the entrance to blind-ending basins in low turbidity areas. The mechanism by which such shoaling occurs has been appreciated for many decades (Rehbock 1917, Röhr 1934).

Indeed, a conflict of interests at the entrance to blind-ending basins in low tidal range sites has long been recognised. In order for ships to safely enter the basin the entrance needs to be as wide as is practicably possible. On the other hand, the wider the entrance the greater the silt penetration. Addressing this dilemma has proved intractable over eight decades.

Studies have recognised that silt intrusion can be minimised in the case of tidal basins by narrowing the entrance to an axial cross-section which admits no more than the tidal volume of water. At the

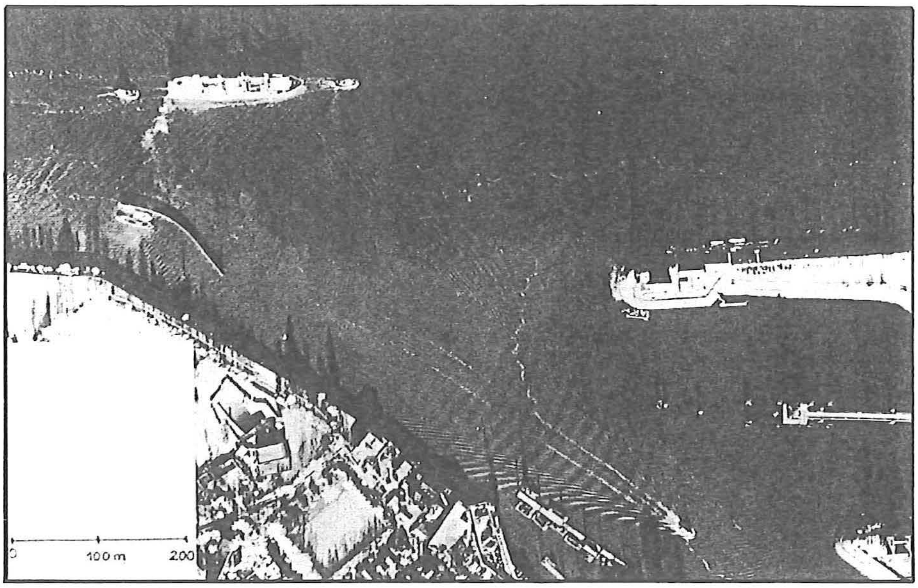

Figure 3: aerial view of prototype Current Deflecting Wall in the Köhlfleet entrance in December 1990.

same time this was recognised to be impractical on grounds that ship entry would then be almost precluded.

Experiments aimed at passive reduction in silt penetration at model scale have been made by varying bed topography and entrance configuration, with no benefit. Active fixed dredging systems such as air bubble curtains have been shown to exacerbate the problem. Arising from these failures conventional dredging methods have continued to be employed.

However, the issue is too important to have been ignored for long. In the case of the large blind-ending harbour basins in Hamburg, the mean annual dredging need amounts to 2 million tonnes/yr, reaching 4 million tonnes/yr during extreme conditions.

All the mud deposition and hence mud dredging is in basins, as opposed to channels, and the deposits are very highly contaminated. Long term monitoring indicated that mud dredging was inversely proportional to river discharge in the Elbe and that anywhere between 60-85% of all mud deposition was focused in entrance shoals, which in some areas accreted at the rate of 3.0m/yr. Such a rapid rate of deposition severely taxed the harbour authority, requiring frequent dredging effort.

Moreover, the technique employed, using moored bucket ladder dredgers, further imposed a navigational hazard in these sensitive entrance regions. Added to this the cost of dredging, treating and disposing of such material on adjacent land has proved very high.

During the late 1980s attention became focused once more on trying to understand the processes leading to eddy-induced entrance shoaling, with a view to reducing the scale of these inputs by passive means. The mechanism leading to eddy-induced shoaling in general is well known (figure 1), as are the various mechanisms by which water and sediment exchange at wide basin entrances is effected (figure 2).

Hamburg is a tidal but fresh water port, with the result that tidal filling and horizontal mixing are the dominant exchange mechanisms. Based on this understanding, thinking became focused on passive means by which the eddy, which induced the shoaling, might be suppressed.

Eventually thought became concentrated on the possibilities for a large full water depth vane or wall located around the upstream corner of the basin entrance. The device became known as the Current Deflecting Wall (Christiansen 1987).

The current deflecting wall

The purpose of such a device was to minimise and push towards the channel the mixing zone induced by flow separation at the upstream corner, to kill the eddy and by application of a low sill across the CDW entrance to drive away any near-bed enhanced turbidity zone. In model tests, correctly configured CDWs gave rise to a number of characteristic flow modifications. All tidal filling was accomplished via the CDW channel. The induced inflow parallelled the axis of the basin, other than in the entrance-region, where a slight over-catchment ensured that an outflow was generated across the larger, unenclosed entrance.

In tidal situations it was judged that a CDW would only be necessary on the flood tide corner, on grounds that although an eddy is generated on the ebb phase too, water is advecting out of the basin at this time. Studies of the fundamental effects of such a device appeared to indicate two subtle aspects.

Firstly, the device appeared to work by removing the initial force leading to eddying as opposed to setting up additional forces (Smith & Kirby 1992).

Secondly, the CDW channel cross-section is precisely that of the ideal minimal entrance to permit tidal filling alone, but is shifted from the axial zone to the upstream corner. Furthermore, the physical wall of the 'ideal solution' referred to earlier, is replaced instead by a wall of water, the outflow, which ships can penetrate but which deflects sediment.

Hamburg provided an almost ideal testing ground on two counts. Firstly, there is a long and well-established inverse relationship between river discharge and siltation rate in all basins in the port. When the river discharge in the Elbe is low the turbidity maximum migrates eastwards into the harbour. This provided a reliable source of information to estimate what the siltation rate would have been in the absence of the device once it was installed.

Secondly, Hamburg also has a large number of other basins, providing an alternative check on siltation rate without a CDW installed.

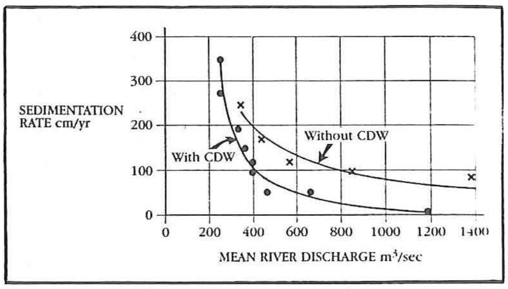

Figure 4: graph of mean river discharge (m^3/sec) versus sedimentation rate (cm/yr) for Köhlfleet prior to CDW installation (1982-1989) compared to after CDW installation (1990-1995).

Following model testing and comparison with the prototype, a full scale CDW was built at the entrance to the 2.5km long Köhlfleet basin in Hamburg, being completed in November 1990 (figure 3).

Monitoring immediately proved that the anticipated modifications to water flow in the basin had been achieved. Monitoring the influence of the device on siltation rates in and around the CDW has taken a much longer period. Data for 5.5 years is now available.

The data shows categorically that sediment is not driven deeper into the Köhlfleet basin and neither is it redistributed into adjacent basins. The Elbe fairway is sandy and no fine sediment is redeposited here either. In the basin entrance no shoal now forms and the siltation rate has reduced by about 50%, a mean of about 140-170.000m^3/yr. The 'production' rate of the system is about 17m^3/hr. The remaining suspended sediment input is spread on the basin bed as an even layer.

The reduced total input and negligible peaking of deposition results in much extended time periods between dredging operations. The sediment which formerly deposited in the entrance shoal returns to the main channel after a short excursion into the basin entrance. It has been calculated to represent close to 0.8% of the flood tide flux and thus to be indistinguishable above the normal low background.

Over the 5.5 year period the discharge of the Elbe has varied across the complete span from a low minimum to a high maximum. Quarterly echo sounder monitoring provides data for a performance curve confirming benefit across the full spectrum of natural conditions (figure 4).

At the cost of dredging, treating and disposing of the mean 140,000m^3/yr of contaminated sediment, the payback time for the design and construction is 1.25 years.

The passive CDW has no moving parts, requires no power and will require negligible maintenance. Having paid for itself, its benefit will now continue in perpetuity.

Arising from the proof of this benefit, together with confirmation that it is realised at all tidal and river discharge conditions, Hamburg Port Authority are now embarked on a policy of building as many further devices as are economically justified as rapidly as financial allocation can be provided.

A completed second-generation design for the next basin eastwards from the Köhlfleet, at Parkhafen, is in being and preliminary design studies for Vorhafen, Kohlenschiffhafen, Sandauhafen and Südwest/India/Hansahafen have been carried out.

It is obviously difficult to 'see' a submerged and passive device actually working but development of ADCPs in silt tracking mode with verifiable concentration calibrations now permit this.

Flood tide 'instantaneous' plots of depth measure suspended sediment concentration, together with current speed and direction at Köhlfleet with a CDW and adjacent Parkhafen without one show pronounced contrasts.

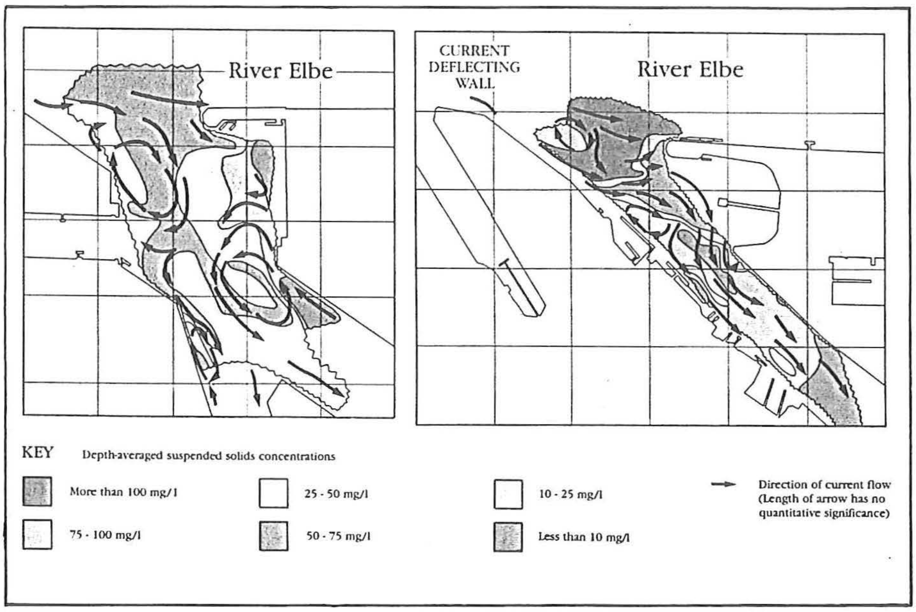

Figure 5: ADCP records obtained by Dredging Research Ltd showing main current vectors and suspended sediment concentrations on the flood tide in two adjacent harbour basins in Hamburg, one with and one without a Current Deflecting Wall, showing how the device kills the eddies and prevents suspended sediment penetrating deeply into the basin. The records show in the immediate term how benefit shown graphically in the long term in Figure 4 is achieved.

Sediment penetrates more deeply into Parkhafen and 'swirls' into the stable eddy systems to be trapped and settle out onto the underlying shoals, figure 5.

In keeping with any system, the CDW has secondary impacts. Initial concern was expressed by harbour pilots about the obstruction to navigation caused by the device.

Using a ship-simulator, 2000 approaches have now been made to Parkhafen, without any problem. During the 5.5 years the device has been in place at Köhlfleet pilots have gained practical experience of its influence.

By eliminating cross currents in the eddy it has been found that handling large tug-assisted vessels in the entrance has become easier, a finding assisted in no small part by there never, or only rarely, being bucket ladder dredgers and hopper barges moored in this region.

The Current Deflecting Wall also provides a very significant water quality benefit compared to previous practice. Conventional dredging entrains anaerobic bed deposits leading to a high local dissolved oxygen burden and desorption leading to remobilisation of contaminants.

Prior to the reunification of Germany dissolved oxygen in the river waters of the Elbe reaching Hamburg were critically low for 5 summer months. During these time periods conventional dredging was sufficient in places to drive the oxygen demand across the threshold, leading to deoxygenation.

A combination of improvements since reunification, in part aided by the use of the CDW, now result in the river through Hamburg remaining aerobic in summer months. Naturally, there is also an environmental benefit arising from reduced contaminated mud disposal need ashore.

Now that the prototype CDW is proven in Hamburg and further and more sophisticated configurations of the system are being conceived for additional basins, the concept is ready to apply elsewhere.

It is already clear that the CDW will work in small as well as in these large basins and is applicable to new as well as to existing basins.

The device will obviously work in the sea, rivers, lakes and certain reaches of estuaries where sediment intrusion is dominated by horizontal exchange and tidal filling.

Experiments are in progress in order to assess the extent to which this concept is applicable to situations where significant density-driven vertical circulation occurs.

In addition to its applicability to reducing dredging need it seems likely that CDWs can be used to reduce siltation in irrigation systems, to counter coast erosion from certain causes and to improve water quality in blind-ending basins.

Conclusion

There has been an 80 year delay between appreciating the process inducing the greatest amount of siltation in blind-ending basins and devising a passive solution which minimises inputs.

Passive dredging devices such as the CDW meet the challenge of the 21st Century by not only serving their primary purpose of reducing fixed port operating costs, but also achieve it without any detrimental environmental downside. Although an apparent impediment to navigation, entrance penetration by vessels, in several respects not drawn out here, is eased.

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