Transactions on the Built Environment vol 40 © 1999 WIT Press, www.witpress.com, ISSN 1743-3509

Model study to reduce siltation in harbours using current deflecting walls

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Abstract

A common problem for port authorities around the world is that of shoaling in harbour basins, caused by the deposition of sediments transported by flow in adjoining channels. In order for port authorities to operate efficiently the deposited sediment has to be dredged regularly.

Major benefits have been achieved in reducing this sediment build-up in harbour entrances and basins by a new passive device known as a Current Deflecting Wall (CDW). The device is a full height curved wall, located at the upstream corner of a basin entrance. Currently the only way to design a CDW is by physical hydraulic model studies, which are costly and time consuming.

The paper describes recent research undertaken at Delft Hydraulics in The Netherlands to study the design of CDWs. From this research it has been possible to: (i) quantify the influence of a CDW in the mouth of a basin on the flow pattern and potential siltation processes, (ii) understand the mechanisms by which the CDW operates, and (iii) propose the optimum design criteria for a CDW. The research undertaken demonstrates the sensitivity of the location of a CDW for the sediment fluxes, and also illustrates, from laboratory results, the complex flow regimes associated with such a device.

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1 Introduction

The entrainment and subsequent deposition of sediments in tidal basins from the oscillatory flow in adjoining estuarine channels is a natural occurrence and one which can cause major managerial and financial problems for port authorities around the world. In order for port authorities with serious siltation problems to operate efficiently, and to allow the safe passage of vessels of steadily increasing size, sediments often have to be regularly removed by dredging. This has a major annual cost implication for port authorities, and one which has escalated in recent years, mainly due to the recent introduction of tougher legislation aimed at protecting the aquatic environment. If the sediments are polluted, as is often the case in heavily industrialised areas, then the cost of removing the dredged material can become significantly higher.

The CDW is a major innovation in the quest to reduce the sediment build-up in harbour entrances and basins. Long term monitoring in the Köhlfleet basin, Hamburg, where one of the first full scale prototype CDWs has been built, shows a 50 % reduction in the annual siltation rate.

2 Study Details

2.1 Collaboration

Collaboration between Bradford University and Ravensrodd Consultants (UK), Franzius Institut and Hamburg, Strom und Hafenbau (Germany) and Delft Hydraulics (the Netherlands) has enabled this study, funded by the European Union as a contribution to LIP-II, to be undertaken. The objectives have been to investigate and quantify the influence of a CDW placed in the mouth of a basin on the flow regimes, which have implications for the siltation processes occurring within the basin.

2.2 Current Deflecting Wall

The CDW device is a full height, curved wall located at the upstream corner of a harbour or basin entrance. Its purpose is to guide the flow into the basin and to avoid separation from the upstream corner of the basin. Although separation may occur behind the wall, the mixing zone is suppressed and sediment entrainment is reduced. A low sill at the upstream base of the wall is used as a means of deflecting that part of the water column which is highly laden with sediment away from the harbour basin and towards the main watercourse. This allows water with much less suspended sediment to fill the basin during tidal filling. Figure 1 depicts schematically a typical flow configuration for a harbour basin both with and without the use of a CDW.

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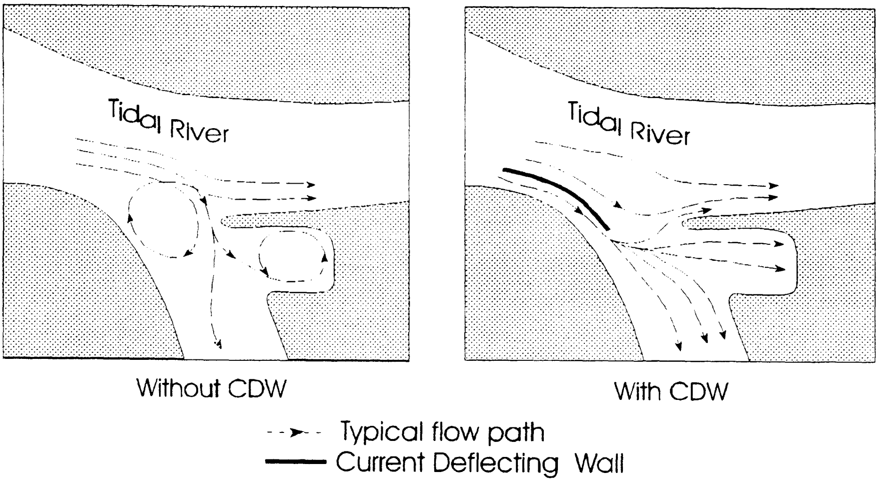

Figure 1 - *Typical flow configuration for a harbour basin both without and with a CDW.*

It can be seen from this schematic illustration that the aim of using the CDW is to reduce or eliminate the tide induced circulation and eddies and to reduce any mixing that occurs across the entrance to the harbour. This elimination of the tidal eddy, or diminution in its strength within the basin then reduces the entrainment and deposition of sediments in the basin.

2.3 Siltation Processes

There are various processes by which the sediment from the silt laden waters of rivers and estuaries can be transported into the relatively low turbidity waters of docks and harbour basins. They include (Krunningen et al [1]): (i) the filling and emptying of a harbour by the tide (tidal effect), (ii) diffusive water exchange (mixing), between the main flow in the river and an eddy in the harbour entrance (horizontal exchange), (iii) density currents induced due to an oscillating water density in front of the harbour entrance over the tidal cycle (i.e. density driven flow), (iv) density currents induced by a fluid mud layer passing by the entrance (turbidity driven flow), and (v) other mechanisms such as the withdrawal of water from the harbour. For this study, the diffusive water exchange (i.e. mixing), and tidal exchange have been the two main processes investigated.

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3. Laboratory Work

A comprehensive series of tests were undertaken using model CDWs sited in idealised basins in the tidal flume at Delft Hydraulics. Full details are given in Crowder[2].

The test facility at Delft Hydraulics allowed both steady state and unsteady state (or tidal) tests to be carried out, although most of the testing was undertaken for steady flow conditions, with various discharges from the inner blind end of the basin to simulate tidal filling. During the latter period of the study, investigations were made with the most promising CDWs under tidal , or reversing flow, conditions.

The performance and sensitivity of CDWs of various configurations were rigorously tested including, in particular, variations in size, shape, position and configuration. Tests into the effects of the basin entrance configuration, the inclusion of a sill and the sensitivity of the head of the wall, i.e. - the nose profile, were also undertaken.

3.1 C-Shaped Walls

In all, seven configurations of C-Shaped walls each consisting of one or two elements, were tested without a sill. The placement of these walls was by trial and error and loosely adhered to the positioning criteria (Crowder[2]) which was deployed to asses the performance of each wall.

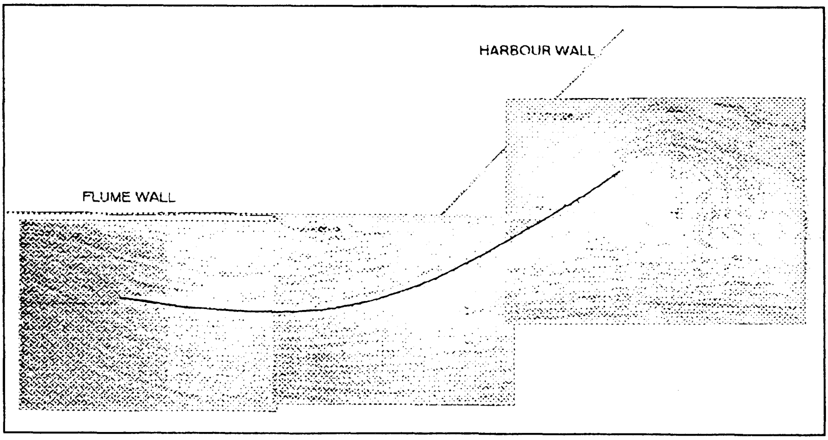

Figure 2 : *Stream pattern at the water surface around CDW No.1 (PIV measurement)*

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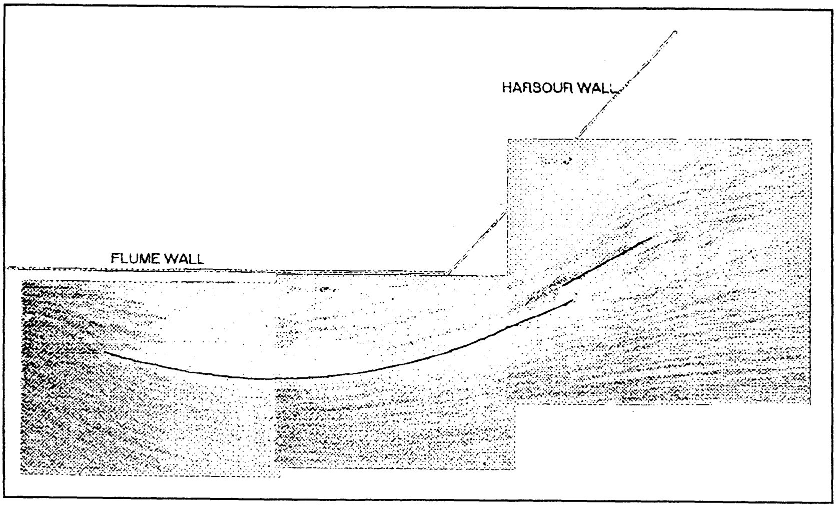

Figure 3 : *Stream pattern at the water surface around CDW No.8 (PIV measurement)*

Figures 2 and 3 illustrate Particle Image Velocimetry (PIV) results from two of the walls tested. It can be seen from Figure 2, i.e. a single element wall, how the flow is smooth and attached to the leading section of the wall (left hand side) but then separates and produces a large mixing region at the tail of the wall and across the harbour entrance. However in Figure 3, i.e. a double element wall, the flow is attached to the wall along its whole length and directs smooth flow into the basin and results in a significantly suppressed mixing region across the basin entrance. It was found that the performance of the CDW could be affected by even small changes in position of the leading edge, the position and angle of the second element, and the general shape and position of the wall. Through detailed velocity measurements it was possible to establish, for the various harbour discharges investigated, the complex flow regime that existed both through the CDW channel and across the harbour entrance.

3.2 Harbour Entrance Configuration

During testing it became apparent that the shape of the downstream corner of the entrance to the basin affected the flow regime across the entrance. Investigative tests were undertaken for 18 different profiles of the downstream corner to see if any improvements could be made to the flow regime. Results indicated that benefits could be obtained with profiles that smoothly separated and guided the flow, either into the basin or back towards the flume.

3.3 Sill Attachment

The attachment of a low sill at the leading edge of the CDW was investigated. Sills proved to have a beneficial effect on flow. An optimum height for the sill was found to be 5 cm (i.e. 25 % of mean water depth), with the sill deflecting the near bed flow away from the harbour entrance without: (i) degrading the flow regime through the CDW channel, or (ii) promoting entrainment into the harbour.

3.4 Nose Profile

From the onset of testing it became apparent that great care had to be taken in siting the leading edge of the CDW if flow separation and eddy-shedding were to be avoided in that region. One of the factors considered to be producing this sensitivity (2-5 mm of freedom) was the curved shape and the associated circulation around the structure[1,2,3]. In an attempt to reduce the effects produced by the circulation and also to reduce the sensitivity to placement, several rounded attachments to the leading edge of the CDW were studied. It was found that by including such an attachment a significant amount of freedom (up to 10 cm) could be obtained in the siting of the leading edge, while allowing flows to remain attached to the wall.

4. Discussion

This study has established a number of new criteria for the design of a CDW and has also clarified some of the complexities associated with such a device. A wall made from a single element can be of significant benefit, but one which is made of two elements, though more difficult to place, has been shown to produce superior results. It was clear that a CDW is acutely sensitive to siting and that this can only be truly addressed when a greater understanding of the physical phenomena are available. The peripheral CDW design aspects such as the nose profile, a low sill attachment and the downstream basin corner configuration, have all been shown to be crucial elements if the flow regime in both the CDW channel and basin are not to be significantly impaired. The CDW can be an extremely effective device in suppressing the scale of the entrainment mechanisms which in turn have implications on the sediment build-up in harbours. The success of the CDW has created much interest, especially by the Hamburg Port Authority, and now requires further study if this new device is to be optimally designed and constructed in an economical way.

5. Conclusions

The main findings from this comprehensive laboratory study can be summarised as follows:

(i) The most effective CDW configuration has been that with two elements. This configuration diverted the flow smoothly into the basin, significantly reduced the size and influence of the mixing zone and reduced the exchange between the flume and the basin.

(ii) Rounding the leading edge of the CDW reduced the risk of flow separation along the length of the wall and also reduced the sensitivity of the wall location.

(iii) Refinement of the shape of the downstream corner of the basin appeared to improve further the performance of a CDW.

(iv) The addition of a low sill across the inlet of the CDW allowed the near-bed flow to be diverted smoothly away from the basin without degrading the flow regime.

(v) A complex 3D flow regime existed, both in the CDW channel and across the basin entrance, and attempts are now being made to model numerically these complex hydrodynamic processes.

Acknowledgements

This research study was undertaken as part of a Large Installation Plan II project, funded by the European Union and undertaken at Delft Hydraulics in the Netherlands. The Institution of Civil Engineers Research and Enabling Fund also allowed the first author to undertake the experimental work at Delft Hydraulics. The authors are grateful to the other members of the scientific committee who helped to guide this project.

The current deflecting wall invention is protected by European and North American patents.

References

1. Krunningen, F.E. van, Eysink, W.D. and Winterwerp, J.C. *Parkhafen in Hamburg; Investigations on the effect of a current Deflecting Wall on the sedimentation in the harbour basin, Part One.* Delft Hydraulics, Netherlands, Report Z512, October 1992

2. Crowder, R.A. *Study on the Reduction of Siltation in Harbours by Means of a Current Deflecting Wall,* Final Report. Department of Civil and Environmental Engineering, University of Bradford, UK, February 1996.

3. Smith, A.M.O. High-Lift Aerodynamics. In : *Proceedings 37th Wright Brothers Lecture*, Vol.12, No.6, June 1975, pp.505