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The development of scour holes in a tidal area with heterogeneous subsoil under anthropogenic influence

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Introduction

The Rhine-Meuse Delta is located in the most densely populated and most used part of the Netherlands. To guarantee safety it is of great importance that the dynamics of the riverbed are closely monitored. At the moment there are over 100 identified scour holes in the Rhine-Meuse delta of which some still grow, (Huismans, 2016). In the development of these holes the heterogeneity of the subsoil plays an important role, (Huismans, 2016; Sloff, 2013). The subsoil lithography is composed of alternating layers of poorly erodible clay and peat and highly erodible sand, (Berendsen, 2001; Hijma, 2009). At locations where the clay or peat layer becomes too thin due to erosion, exposure of an underlying layer of sand can result in a scour hole, see Fig. 1. Since these holes and their steep slopes may pose a risk to the stability of riverbanks, dikes and hydraulic structures, knowledge on their development is required. In this paper a thorough analysis of field data and results of a physical scale model is presented.

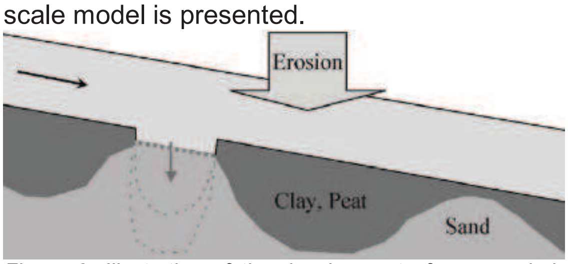

Figure 6. Illustration of the development of a scour hole in heterogeneous subsoil, (C. Sloff, 2013)

Method

The method consists of three steps:

1. Analysis of a large set of scour holes in the field.
2. Physical scale model tests to study the detailed growth.
3. Link the scale model results to the results from the field data analysis.

Field data analysis

A tool has been developed to visualize the evolution of the deepest points of a river branch per cross section based on bathymetric surveys of the period 1976-2015 provided by Rijkswaterstaat. The result shows the overall development of the deepest parts of the entire river and therefore the locations of the scour holes and their development. With the use of additional information on the scour hole profile, the heterogeneous subsoil, human interventions and other changes in hydrodynamics, these plots shed light on the scour hole development over time and their possible causes.

Physical model

To study the development of a scour hole in heterogeneous subsoil the following experiment was carried out. In the Waterlab of the Delft University of Technology a flume of 12m length, 0.8m width, 0.25m depth was constructed. The entire bottom consisted of a layer of cement except for an oval opening in the centre of 0.5m length and 0.3m width. The cement layer surrounding the oval, covers a box of sand. The flume simulates a river with a non-erodible bed and a local discontinuity in the top layer exposing an underlying sand layer. This way a scour hole could develop in the oval opening. Using scaling rules a representative water depth and flow velocity were chosen of respectively 0.13 m and 0.45 m/s and fine sand with a d_{50} of 260 μm. Experiments were also done using materials similar to clay partly covering the oval opening. The materials used were river clay and fine sand hardened with sprayed paint. These experiments aim at creating a better understanding of 3D effects introduced by the shape of a scour hole. Moreover, the behaviour of a poorly erodible bed can be simulated that also has the ability to fail.

Results

Field data analysis

The Oude Maas was chosen as the first river branch to analyse. In the river a total of fifteen scour holes were identified. The developed tool shows a different development per hole in time and space, which is illustrated with three holes in Fig. 2. Typical scour hole development shows a negative exponential growth rate, with a fast initial growth and a stable end state, (Hoffmans, 1997). This profile is found for a part of the scour holes, showing large growth at a certain time and ending in a stable state. A sudden step in growth can possibly be related to a breakthrough of the layer of 'Wijchen', a clay layer which spreads over the whole delta and covers the Pleistocene sand. Its level at the location of the scour hole is also indicated in the figure with the dashed line of the same colour. Other holes which recently developed are still growing and have not reached their possible equilibrium. However, there are exceptions that behave completely different and can possibly be related to other causes.

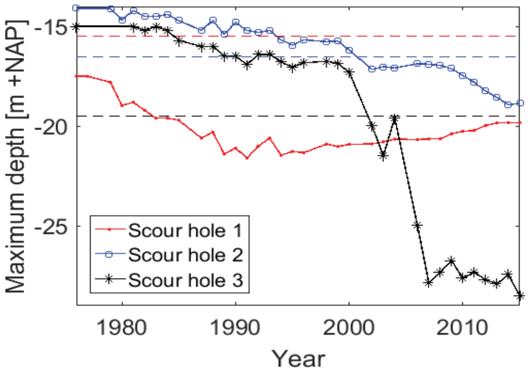

Figure 7. Development of the deepest point of three different scour holes in the Oude Maas in the period 1976 – 2015. The dashed lines indicate the layer of 'Wijchen'.

The results show that nine out of fifteen holes already existed before 1976. In 2015 eleven holes seem stable and four are still growing. To determine the influence of river discharge a comparison will be made with high river discharges and scour hole growth. Furthermore, the slopes of the scour holes in the field will be compared with the suspected slopes from the theory. Finally, these analyses will be continued for the other river branches in the delta as well.

Physical scale model

Fig. 3 shows the scour after 4 hours. During the whole experiment the upstream slope appeared to have a constant value of 1:2. At the downstream edge and partly on the sides undermining occurred after a certain time. Compared to the 2D experiments, (Zuylen, 2015), the 3D experiments showed a faster growth of the scour hole. The 3D experiment did have a smoother upstream surface than the 2D experiment which could have enhanced the growth. The experiment with the spray paint layer showed the best agreement with the behaviour of clay. During the experiment the undermining process and subsequent growth in width and length could be visualized.

Discussion

To compare the scale model to the field the scour depth over the water depth is used. The results are in the same order of magnitude. In the field erosion of the upstream edge of a scour hole is observed, which is not found in the scale experiment. This could be the result of the presence of a thinner clay layer upstream of the scour hole or the tide that reverses the flow direction.

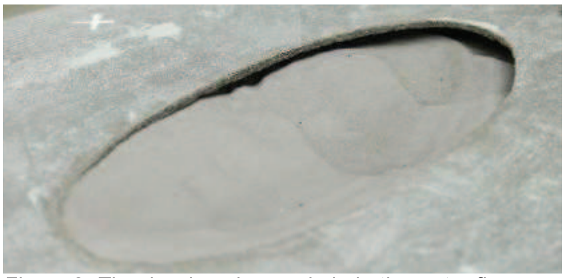

Figure 8. The developed scour hole in the water flume after 4 hours.

Conclusion

The development of scour holes in the field is very variable, also when they are located in the same river branch. The development is therefore likely to be related to the heterogeneity of the subsoil and local phenomena in the flow conditions. The scale model shows only undermining of the downstream edge. The upstream slope stays constant and has a value of 1:2. Scour holes in the field show different behaviour which could possibly be the result of the tide or variation of the thickness of the surrounding clay layer. In future research, a comparison with the theory, the scale model and the field data will be made.

Acknowledgements

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