Jun 1st, 12:00 AM

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Recommended Citation
Arthur Marsland, "Failure of flood banks due to under seepage" (June 1, 1988). International Conference on Case Histories in Geotechnical Engineering. Paper 21.
http://scholarsmine.mst.edu/icchge/2icchge/2icchge-session3/21

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Failure of Flood Banks Due to Under Seepage

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SYNOPSIS:
Several failures of floodbanks caused by increases in water pressure and seepage in foundation soils during abnormal high floodwater conditions have been investigated. The particular type of failure which occurred depended upon the sequences of the foundation strata, the overall bank profile, and the height and duration of the floodwater. Both rotational and translational slides occurred in banks built on sands, peats and clays with underlaying sandy gravels. Breaches occurred when the crest was sufficiently lowered to allow substantial overtopping or where gaps developed at the ends of the translational slides. Development of erosion pipes in multi-layered soils led to both partial collapse and breaching of banks. The need to anticipate possible failure mechanisms when evaluating the effectiveness of flood defences is emphasised.

INTRODUCTION
Flood defence banks protecting low lying ground along rivers and coasts are of necessity constructed on alluvial deposits. These may comprise peats, soft clays, silts, sands and gravels. Wherever pervious strata outcrop on the foreshore or in river channels increases in groundwater pressures and flow gradients occur in the strata below the banks during high water conditions. As a result of these changes overall instability of the banks or the development of erosion pipes in unstable strata can occur. Rapid breaching and extensive flooding can result from both types of failure. The examples of failures described in the following sections have been drawn from the author's records in order to illustrate the various types of under seepage failures which occur in Britain. Studies of failure mechanisms and of conditions conducive to potentially dangerous under seepage form an essential requirement for the adequate assessment of the effectiveness of flood defences.

FAILURE OF BANKS BUILT OF FINE SAND
Recent deposition under the tidal conditions occurring along the coastal and estuaries of Britain has resulted in soil profiles comprising a relatively thin layer of silty clay overlying fine sand. The thickness of the overlying silty clay present under the flood defence banks depends on the length of time deposition has occurred prior to construction of the banks. In the marshes along the east coast of Essex where a number of breaches occurred in the banks during the abnormally high tides in 1953 the silty clay is 1 to 2 metres thick. Fortunately most of the banks have extensive saltings on the seaward side and their blanket effect prevents large changes of pore water pressures occurring in the underlying sands. As a consequence most of the breaches followed the development of shallow slips in the fissured backslopes of the banks (Cooling and Marsland 1954, Marsland 1957, Marsland 1984) and were small or only partially developed. However, a very large breach accounting for much of the flooding occurred along a stretch of bank flanking an outfall drain cut through the saltings. A cross-section through this bank is shown in Fig 1(a). The presence of large lumps of clay from the bank more than 120 metres into the marsh indicated that the breach had developed rapidly.

Fig 1 Uplift failures of banks built on fine sand in Essex.

Estimates of the likely pore water pressures which developed in the underlying sands during the 1953 tides were obtained by extrapolation of measurements made during subsequent spring tides. These indicated that equilibrium pressures corresponding to minimal seaward protection had probably occurred. When these pore water pressures were used in effective stress analyses incorporating a range of values of effective stress parameters determined from laboratory tests, factors of safety of between 0.75 and 1.0 were obtained. The available evidence suggested that most of the bank slid into the marsh as the tide reached this maximum level as shown in Fig 1a and this resulted in the formation of a deep wide breach in a very short time.
Further evidence of the critical nature of the stability of these banks during flood conditions was provided by a deep slip which occurred in an adjacent bank fronted by saltings. A section across this slip is shown in Fig 1b. Measurements of pore water pressures during subsequent high tides showed that changes at this location were much smaller than at the breach site. Changes in the level of the water in the landward ditch were quickly reflected as additional changes of pore water pressure in the sand under the bank. A combination of the pore water pressures caused by flooding of the landward ditches and the moderate increases due to under seepage where sufficient to cause the slip.

FAILURE OF BANKS BUILT ON LAMINATED DEPOSITS

Laminated silts, sands and clays are frequently found in the less exposed inner regions within tidal estuaries. The author has no first hand experience of their occurrence especially where the banks are subjected to high flood levels for prolonged periods. Banks built on laminates are, however, prone to failure as a consequence of internal erosion. A serious breach and several other partial failures occurred during 1960 in banks along Elevated drainage channels passing through the silt lands in the Norfolk Fens. A section through the bank at the site of the breach is shown in Fig 2a. The water level in the channel began to build up during 20 December and by midnight had reached + 3.4 m ODN. On 21 December the level gradually increased to a maximum of 3.85 m ODN at 1200 hours. Regular inspections were made of the banks and the drainage ditches on the marsh side until 1130 hours on 22 December when the flood levels had fallen by about 0.3 m. At this time there was only evidence of slight seepage along the side of the landward ditch. However, by 1400 hours silt laden water was observed pouring into the ditch and by 1430 hours a large breach had developed. The bank either side of the breach appeared to be undamaged. The formation of the breach removed all further evidence of the mode of development but erosion holes several feet across had been reported in banks in this area at previous times and as a result of a comparable high water flood in 1947. A photograph approximately 2 metres across and 2.5 metres deep was also discovered in the crest of a bank along a parallel drainage channel (position C Fig 2b) at 1500 hours on 21 December 1960 when large quantities of silt laden water were seen pouring out into the marsh drainage ditch. Fortunately this did not lead to a complete breach and subsequence of over till revealed a horizontal pipe with a diameter of about 230 mm leading to the drainage ditch as shown in Fig 2b. Fortunately the horizontal pipes did not extend back to the main channel during the flood period. All the erosion pipes observed occurred in the laminated clay-silt-sand with the overlying clay and peat providing some roof support. Precise details of how the pipes developed is not known but grading curves on soil from individual lamina suggest that the washing of particles from finer into coarser lamina could have been a contributing factor.

Fig 2 Underseepage failures of banks built on laminated clayey, silty, sandy deposits in the Lincolnshire Fens.

FAILURE OF BANKS BUILT ON PEAT

The gradual back-up of the inland water as the sea levels rose during the retreat of the ice following the last glaciation provided conditions favourable to the formation of peat deposits in shallow lagoons adjacent to many rivers and estuaries. The formation of peat lands has resulted in a considerable lowering of the surface levels due to consolidation, shrinkage, oxidation, and bacterial activity. As a consequence rivers now cross the peats in relatively straight lines through the silt lands in the Norfolk Fens (Johnson 1948 and Summers 1976) could also have developed in a similar way. It was also suggested by Summers 1975 that other breaches in the Fens may have been caused by banks being pushed landward by the pressure of the flood water. Unfortunately, no details of these failures were given. However, in 1976 the author inspected a breach along side a drainage channel in the Somerset levels where this had occurred as shown in Fig 5. Peat extraction in the marsh had made the bank more vulnerable and both the bank and the strip of ground remaining at the rear of the bank moved as an intact unit towards the peat workings. Flooding of the marsh occurred through gaps between the ends of displaced length of bank and the adjacent stable bank.
FAILURE OF BANKS BUILT ON CLAYS AND PEATS OVERLYING SANDY GRAVEL

The flood plain deposits of the River Thames provide a good example of peat and clay sequences overlying sandy gravels (Marsland A 1986). These were deposited on late glacial sands and gravels which were deposited during the later stages of the last glaciation. The major channel of the present day river extends down into the gravels. Along the middle Thames pore water pressure changes equal to more than 50% of the twice daily tidal change (Spring tide range about 6 m) have been measured in the gravels below the marshes just landward of the flood banks. Detailed studies of these pore pressure changes (Marsland and Randolph 1978) have shown that the percentage response increases when tidal surges are superimposed on normal sinusoidal tides.

In the not too distant future, abnormal combinations of spring tides and tidal surges could cause uplift pressures in the gravels sufficient to float the existing layers of peats and clay (up to 7 metres thick) present in the marshes along parts of the Thames. The pore water pressure responses in the gravels along the tributaries of the Thames are much less but so are the thicknesses of the peats and clays. A 28 metre long breach occurred in the bank along the tributary of the Thames at Dartford during the abnormal tides of 31 January and 1 February 1953 (Marsland 1961).

The breach occurred at a locality where the thickness of the peat and clay was only 1.8 metres as shown in the section in Fig 6. Direct extrapolation of pore pressures measured in the gravel near the breach side over normal tides indicated that floatation of the peat and clay in the marsh had probably occurred before the bank failed. Effective stress analyses confirmed that the bank could have slipped into the marsh under these conditions as indicated in Fig 6. It should be noted that the pore water pressure response in the gravel near the bank was only about 25% of the tidal range in the river due to the presence of a 200 mm thick layer of mud which covered the bed.

**Fig 3** Temporary repairs of a breach caused by uplift pressures in peat below bank. (Near Bythburgh, Suffolk).

**Fig 4** Section through centre line of breach shown in Fig 3.

**Fig 5** Photograph of lateral displacement bank built on peat (Somerset Levels)

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Second International Conference on Case Histories in Geotechnical Engineering
Missouri University of Science and Technology
http://ICCHGE1984-2013.mst.edu
CONCLUSIONS

Under seepage through pervious and semi-pervious strata below flood banks can cause failures and serious breaching. The mechanism of failure at critical locations is mainly controlled by the nature of the underlying pervious strata and the overall profile of the banks. The length of time that the flood water remains near its peak level is almost as important as the maximum water levels reached.

REFERENCES


