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The closure of a leakage in the sealing system of a dyke

L'étanchement d'une fuite dans le système d'imperméabilisation d'une digue

H.ARMBRUSTER, Federal Institute of Waterway Engineering (BAW), Karlsruhe, FRG

G.P.MERKLER, Department of Applied Geology (AGK), University of Karlsruhe, FRG

J.H.M.TRÖGER, Federal Institute of Waterway Engineering (BAW), Karlsruhe, FRG

SYNOPSIS: The measurement of hydraulic, thermal and geoelectrical fields makes the detection of leakage points possible in embankments, i.e. their effects on the relevant area. The example given describes a case of damage, where the position on the leakage in an embankment on the water-side was known, but where the measurements were necessary to ascertain the length of the stretch requiring repairs and to establish the success of the measures taken. The repairs were carried out with the help of a hydro-cut diaphragm wall at a medium depth of 25 m.

1 GENERAL

The redevelopment of the Upper Rhine between Basle (Switzerland) and Karlsruhe (West Germany) began in the 19th century. The meandering river with a total width of up to 6 km was reduced in length by about 23% by straightening it and by means of a dam system running parallel in the hinterland the flood water was kept in a relatively small bed. In the 20th century, when shipping and energy production from water gained great importance, the river barrages were built in the Upper Rhine, which at the same time counteracted the erosion of the river bed caused by straightening it. The dams necessary for this purpose on both sides of the river bed, which is only approximately 250 m wide, frequently cross the old river bed and the numerous old side-arms i.e. the subsoil of the new dams is highly inhomogeneous. It generally consists of alternating layers of sand and gravel down to a depth of about 100 m with fine sands several meters in thickness embedded inbetween. Also partly sandy silt or even a layer of clay can be found at a depth of about 25 m. However, taking the areas as a whole, it cannot be said there are separate ground water reservoirs.

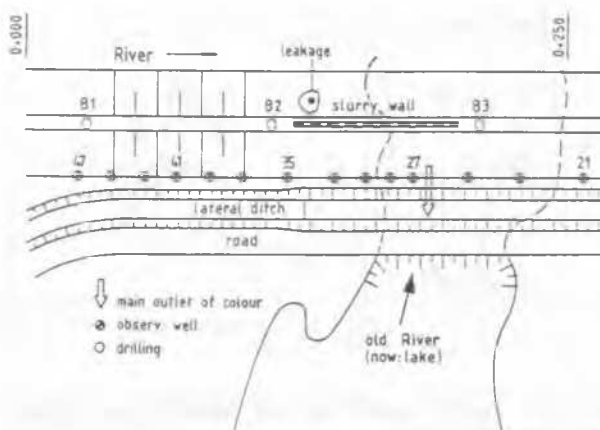


fig. 1. Layout of the dam, observation tubes

2 CONSTRUCTION

The lateral dam of the Rhine, which is about 10 m high at the point observed (fig. 1,2) was

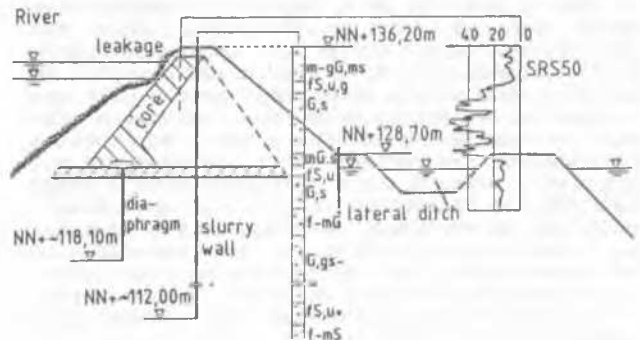


fig. 2. Cross section with drilling and driving rod tests

formed using sandy gravel from the Upper Rhine Gorge, after which the existing fine grained top layer (1 ÷ 2 m) had been cleared away to a large extent, at least in the area of the toe of the dam. In order to limit the seepage through the dam to the required amount 1 l/s.m, it was necessary to provide a dam sealing and partly a subsoil sealing, since the upper gravel layer of the subsoil was only slightly sandy and was thus highly permeable ($k > 5 \cdot 10^{-3} \text{m/s}$). The dam sealing consists of silty fine sands at least 2,5 m thick (economic core) and where sufficient material was available full core was used (dashed line).

The sealing of the upper gravel layer was achieved by means of a diaphragm wall, which was sunk from the base of the dam, before the construction of the dam. A connection between the wall and the core was made by laying the head of the wall bare. The embankment consists of the sandy gravel in the subsoil (fig. 3).

In order to drain away the seepage water, a lateral ditch runs parallel to the axis of the

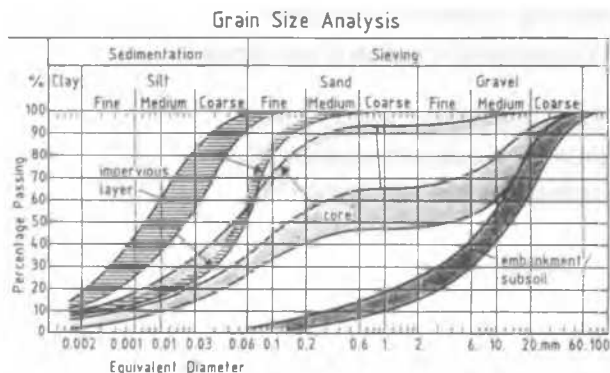


fig. 3. Grain distribution curves of the dam and subsoil

dam, which at the same time takes water from small streams, which serve to drain the hinterland or have to be rerouted due to the construction of the dam.

3 CAUSE OF THE LEAKAGE, IMMEDIATE MEASURES TAKEN

In the summer of 1987, when the damming was partly reduced (fig. 1), a sinking hole was found in the water-side of the embankment, into which approximately 10 l/s gurgled through. On the dry side of the embankment in the air no outflow of water could be seen, either at the dam toe or in the lateral ditch, so that a concentrated flow over a short distance was not expected, however, the possibility of a water leak via a possible pipe in the lake nearby could not be excluded. Consequently a decision was made in-situ to fill in fine material on the water-side, in order to plug the pipe, which obviously existed at least in some areas. In the next 5 days approximately 5 m³ sand were washed into the sinking hole.

4 MEASUREMENTS, PHASE 1

When the leakage occurred observation tubes 21, 23, 25 and 27 (fig. 1,2) already existed, which measure the water level and the temperatures in the berm (pipes approx. 4 m deep). Afterwards pipes 29 to 41 were driven into the holes prepared by driving rod tests. Further driving rod tests were carried out on the crest of the dam in a 2 m grid on both sides of the seepage point. While the filling-in was still being carried out, a colour tracer (Uranin) was inserted into the sinking hole, which already came out after 2 hours at one point in the lateral ditch (fig. 1), and after 3 hours however at several points. No colour tracer was observed in the lake.

The electrical resistance of the embankment and the berm was measured according to Wenner with a grid of 5 m and 10 m and the electrical self-potentials with a 5 m grid too. As a result of the measurements and investigations regarding the subsoil, the following can be stated:

The sealing system has practically no effect.

The cause can be either a defect in the system or a strong underseepage of the wall (or both), however this cannot be definitely ascertained. The seepage spreads out from the leakage mainly over an area and it has created areas of high permeability due to material being washed out, whereby the fine grains of the sandy gravel are flushed out (suffosion) and washed into the pore spaces in the coarse subsoil. This process can only be stopped by reducing the seepage force. Further measuring results will be given in measuring phase 2 (point 6).

5 SEALING

After the first measurements had been taken, it proved necessary to repair the damaged point as quickly as possible. To save money and time, it was decided to seal the area immediately around the point of damage and then to generally change the system later both up-river and down-river. The immediate repairing was to build a wall to replace both the dam core as well as the old diaphragm wall acting as sealing elements (fig. 2). This was then intended to integrate in the sands found approximately 25 m below the dam crest, which were less permeable and thus block the main seepage from the leak. The wall was made using a hydro-cutter for diaphragm walls made by SOLETANCHE and ZÜBLIN (thickness $d = 0,65$ m). The 1st phase (supporting fluid) consists of a bentonite suspension (4 - 6% bentonite, $\gamma = 1,08$ g/cm³), the 2nd phase consists of a bentonite-cement-suspension together with rock flour and sand, which has a density of only $\gamma = 1,35$ g/cm³. Since the difference in density in both phases is relatively small, problems can arise due to the 1st fluid being displaced by the second. Thus the firms use a specially developed substitution frame, whereby the supporting fluid is sucked from the top, whilst the earth concrete is pressed in from underneath. Three factors caused problems during this procedure: There was full seepage in the area of the leakage in the dam, the highly permeable soil layer was partly at depths of over 20 m and the lower level of this layer fluctuated. This became obvious due to occasional, sudden high losses in suspension, which in one case led to collapsing of one slit and finally due to slits at varying depths and occasional

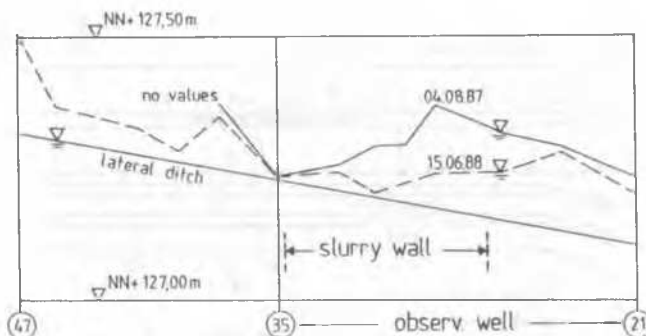


fig. 4. Water table of the observation tubes along the dam toe

changes in the ratios of components the whole wall.

The examination of the samples from the preliminary tests and from the mixtures completed when making the wall showed that the required permeability of $k < 10^{-9}$ m/s (preliminary tests) or $k < 10^{-8}$ (wall samples) and unconfined compressive strength of $q > 30$ N/cm² had been achieved.

The position of the temporary wall (length 70 m) can be seen in figure 1. The construction of the wall took place from 19.10 - 29.10.87.

6 MEASUREMENTS, 2ND PHASE

The measurements of the water table and the temperatures were continued on the extended system in order to determine the success of the sealing measures (fig. 4). The longitudinal section (compare before and after) shows that the phreatic line has dropped between pipes 23 and 33. However, the lowering of the water level at the end of September 1987 (fig. 5) is due to the fact that all vegetation had been cleared away from the lateral ditch and so the water level sank.

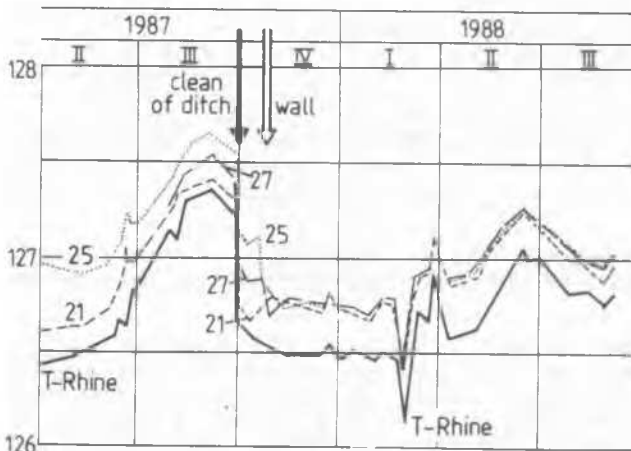


fig. 5. Water table progress lines

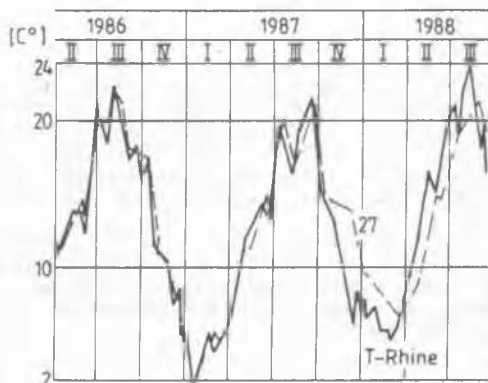


fig. 6. Temperature progress lines of the Rhine and of tube 27

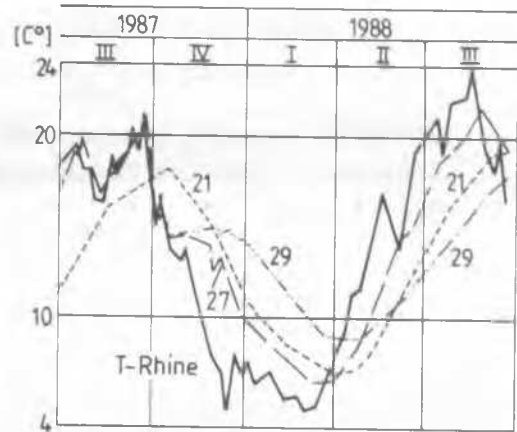


fig. 7. Temperature progress lines at a depth of 4 m along toe of the dam

There is also a change in the course of the temperature, which in the course of time (fig. 6) is clearer than in the longitudinal section. The temperatures at a depth of 4 m below the ground without any sealing are very strongly influenced by the temperature course of the Rhine (slight phase-shifting, a slight differences in the reduction in both amplitudes). After the construction of the wall a clear change in the temperature behaviour can be seen. The amplitudes in the measuring pipes become smaller, the extremes are shifted in phases by about one month (by the most at measuring tube 29 (fig. 7). The sinking of the water table in the lateral ditch resulted in a temperature jump in the measuring pipes. However, there are no typical tendencies after a repair (phase shifting, jump in amplitude).

Measuring tube 21 was already in an area with reduced seepage before, since it is situated outside the former Rhine river bed (fig. 1).

The measurements of the electrical resistance were carried out for 2 different depths of penetration, one of which is shown. Figure 8 a indicates clearly the inhomogeneity of the dam subsoil. The high values (up to 8000 Ω m) clearly indicate dry areas without fine material, which are to be found most, where the colour in the tracer test reached the lateral ditch first. The low values (800 Ω m) in the middle of the embankment indicate an area with far more finely grained dam material, which is attached in a lenticular manner.

The measurements of the electrical self-potentials before the construction of the wall (fig. 8b) clearly show an anomaly in the form of a dipole with potentials between -40mV and +60mV. Numerical modelling according to Corwin/Wilt (1988) using the parameter in figure 8a give an average position of the leak of 6 m below the ground. The calculated results given by the two-dimensional schematic model suggests that the seep area is situated between 2m upto 10 m below the dam crest (high-permeability leakage pathways). The measurements taken about 1 year after the construction of the wall (fig. 8c) no longer show this distinctive anomaly (fig. 8b) and the longitudinal section of the dam crest show fig. 9. This strong percolation due to the leak has thus disappeared due to the construction of the wall.

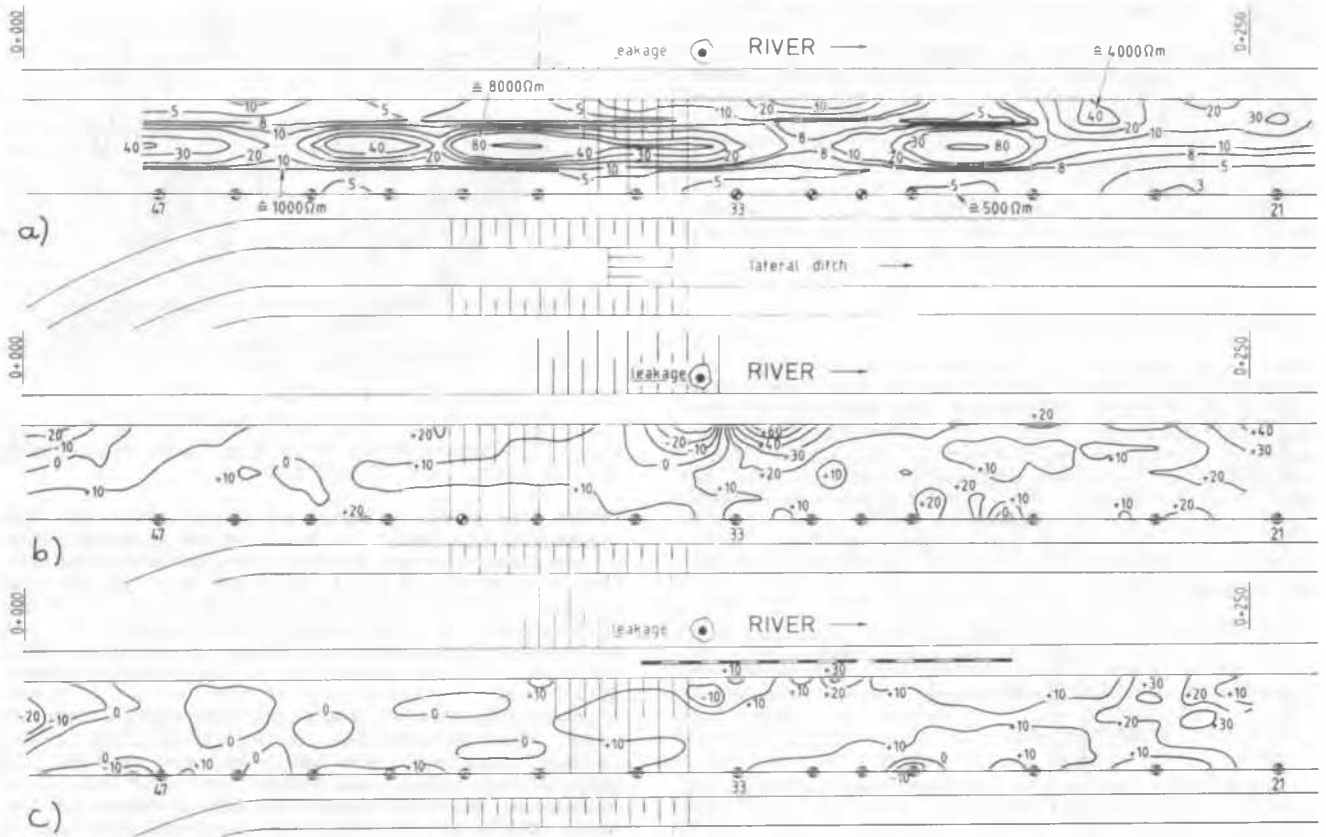


fig. 8. Resistivity and self-potentials: a) resistivity (a = 10 m), measured on 23.9.87 b) self-potentials, measured on 13.10.87 before the construction of the wall c) self-potentials, measured on 27.9.88 after the construction of the wall

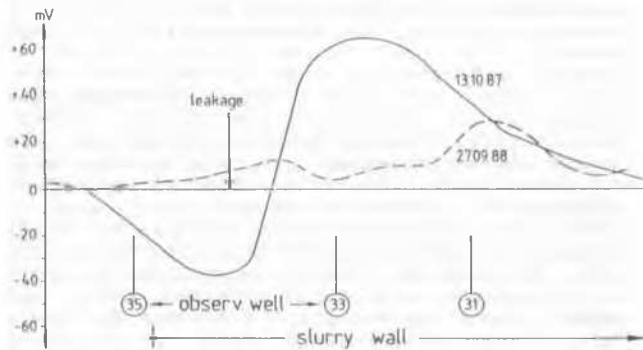


fig. 9. Self-potentials along the dam crest

7 CONCLUSIONS

The measurements taken before the repair of the damage clearly show characteristics of increased seepage over a larger area and which is caused by inhomogeneities of both the embank-

ment as well as the subsoil. After the modifications had been carried out by constructing the wall, which was produced as a hydro-cut diaphragm wall using a 2-phase procedure to prevent the existing seepage the anomalies in the self-potentials disappeared, the phreatic line was lowered and the time course of the soil temperatures changed. This proved that the workings taken had been successful.

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