Permanently flexible and rehardening protective lining of earth material for navigable canals

Une membrane flexible et ré-endurcissante en permanence pour la protection des canaux navigables en terre

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SUMMARY: Underwater installation of new seals is required for lining the existing navigable canals. For this purpose Philipp Holzmann has developed sealing systems using natural clay, which can be installed without disrupting navigation. Depending on the requirements the seals can be permanently flexible or rehardening. The preparation and installation equipment required has also been developed.

The navigable canals in the Federal Republic of Germany were constructed primarily at the end of the previous century and during the first half of this century and no longer meet today's requirements. Damage to the bank and bottom stabilization leads to expensive repairs and interruptions to navigation.

For this reason the system of canals is presently being adapted to the requirements of modern inland navigation with swift vessels by deepening and widening the canal cross sections and replacing locks. This requires removal and replacement of old linings. This work is accomplished under water without interruption to navigation.

The so-called European vessel with a length of 85 m, width of 9.50 m, draft of 2.50 m and capacity of 1350 tons is decisive for expansion of the canals.

One of the three standard profiles below is selected depending on the local conditions:
With banks on both sides,
with bank on one site and pile wall on side,
with pile wall on both sides.

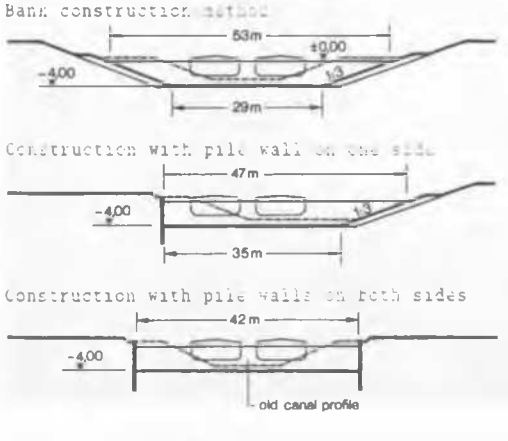

Fig. 1 Standard Profiles

The new canals are protected by linings against navigation stresses resulting from
- sinking and backflow of the water
- the water jet from the propeller,
- lowering the anchor.

In many zones of the canal a seal is required as a part of the lining. This seal can be hard or soft depending on the local conditions.

Linings with hard seals can be installed where settling and deformation are not expected or are expected only to a limited extent.

From top to bottom such seals consist of a 20 - 30 cm thick layer of concrete, asphalt or hoton or an approx. 35 cm thick layer of gravel completely filled with concrete, an approx. 15 cm thick mineral filter, grain size 2 to 32 mm and an approx. 15 cm thick mineral filter, grain size 0 to 2 mm.

In areas where subsequent settling is expected linings with soft seals best fulfill the requirements for bed protection.

From top to bottom these consist of a 45 - 50 cm thick layer of gravel of uniform structure on a mineral or geotextile filter. This is located on a permanently resilient sealing layer with a thickness of 20 - 30 cm.

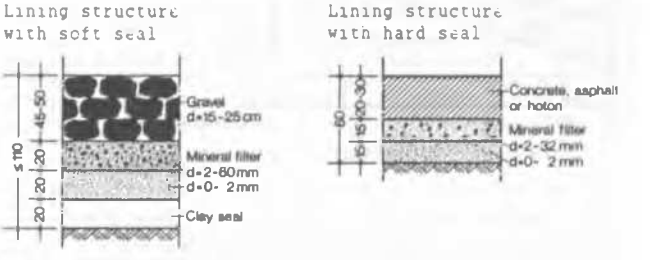

Fig. 2 Structure of linings with soft and hard seals

Since 1978 Philipp Holzmann AG in Frankfurt am Main has been working on developing permanently flexible and rehardening seals using natural clay and has successfully used such seals in a number of canals.

The Holzmann engineers have tested different mixture compositions of natural clay with permanently flexible as well as rehardening properties. These tests have shown that natural clay has specific properties and

requires homogenization to achieve uniform permanent flexibility and workability under water.

On this basis a mixture was developed for permanently flexible seals consisting of 98% natural clay including water and 2& additives. Rehardening seals consist of 20% natural clay and Portland blast-furnace cement, 60% sand 0 to 2 mm and 20% water with slight quantities of additives for stabilization and slower curing.

The technical requirements placed on hard as well as soft seals are:
- flexible, flowing properties must be present during installation so that the seal can be installed without cracks or joints in spite of irregularities in the subsurface.
- the seal must not be dissolved by turbulent currents from the ship's propeller. It must be resistant to erosion until it is covered by the filter and gravel.
- the seal must have low permeability.

Soft seals must also be constructed using permanently flexible material so that the seal can adapt to subsequent changes in the subsurface without cracking.

The quality requirements for soft seals are acheived with the following measures:
- ≥ 80% clay and silt and ≤ 20% sand,
- 2% additives for erosion stabilization and slight stiffening in the final state.
- a k-value of at least 10^{-9} m/sec. for impermeability to water. Homogenization results in uniform distribution of this value throughout the sealing layer.
- an undrained shear strength of 15 - 20 kN/m² is required for permanent flexibility. The water content must not exceed 5%

The grain distribution of the initial material is decisive for uniform quality and permeability of the material. The higher the percentage of ultrafine particles the lower the permeability. The minimum percentage of ultra-fine particles is given in the standard grain distribution curve.

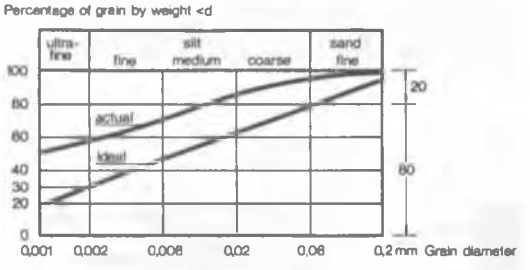

Fig. 3 Grain distribution in clay

The focal points for quality tests in the laboratory are: permeability of the material including joint zones, undrained shear strength and erosion stability.

For rehardening seals tests for checking the desired final strength are also required.

These are comparable to the suitability and quality tests for concrete.

The k-value indicates the impermeability to water. It can be determined in the laboratory using the Darcy method. The k-value decreases with time and is significantly below 10^{-9} m/sec. The execution quality at the construction site was better than the suitability test. Homogenization in a compulsory type mixer assures

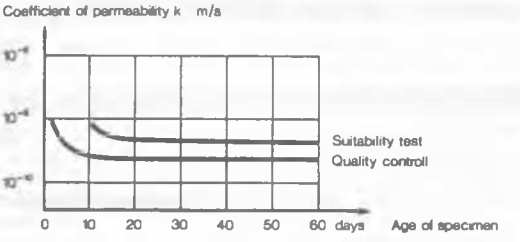

Fig. 4 Chronological development of k-value

a uniform k-value over the entire sealing layer.

The undrained shear strength is decisive for the permanently flexible properties of the seal. It can be measured with the vane probe of a rotation viscosimeter. The undrained shear strength also increases with time. This is the result of the curing process of the binding agent. Since permanent flexibility can only be achieved with low final strength, the percentage of binding agents added is limited to a maximum of 2%

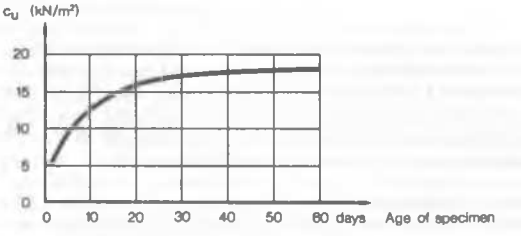

Fig. 5 Chronological development of undrained shear strength c_u

The final concept and the optimum equipment was tested successfully in a pilot plant. The individual elements are:
- Sieve kneader for cleaning and pulverizing the natural clay,
- Box charging device with clay weighing station,
- Compulsory type mixer with special attachments for homogenization,
- Thick liquid pump for transporting mixture to laying equipment,
- parallelogram shaped design of laying arm to assure necessary contact between bottom and mouthpiece on floating laying unit for laying the sealing layers under water,
- and the actual mouthpiece for laying the sealing layer under water.

The operations from preparation to laying the clay and the associated equipment are divided into four units:

1. Land station with sieve kneader for cleaning and pulverizing the natural clay as well as the loading equipment.
2. Chute transport for the clay prepared on land to the laying unit, consisting of preparation and laying boat.
3. Preparation boat with box charging equipment, compulsory type mixer and thick liquid pump with supply silo.
4. Laying boat with mobile laying bridge to which the laying device with mouthpiece for laying the sealing layer is attached.

The boat dimensions were selected to allow the largest

Fig. 6. Laying unit consisting of preparation and laying boat.

possible surface to be sealed from one position and simultaneously not interfer with navigation in the canal during the laying work.

Fig. 7. Laying device with mouthpiece for laying the sealing layer.

The laying device with mouthpiece is mounted to move on a bridge travelling on the legs of the u-shaped pontoon to allow the sealing carpet to be laid in individual stripes. The best width for laying the 20 cm thick strip

Fig. 8. Charging the preparation boat

under water resulted at a mouthpiece outlet width of 80 cm.

The underwater seal was checked continuously by divers and with motion picture cameras to assure that it was laid perfectly without cracks or seams. Based on the knowledge gained with this pilot project the preparation and laying boats for permanent use were built.

The preparation boat is 28 m long, 9 m wide and 2 m high at the side. The following equipment is installed in this boat:
- Cable dredge with grab
- Box charging unit with weighing station
- Compulsory type mixer with volume of 3,2 m^3,
- Angular elevator with 4 m^3-bucket,
- Thick liquid pump with capacity of 33 m^3 per hour,
- Generator unit with capacity of 750 kW.

The clay laying boat is a U-shaped vessel with a length of 33 m and a width of 20 m. It has its own 75 kW power supply. A laying bridge travels along the legs of the U-shaped pontoon. This bridge supports a carriage with a parallelogram-shaped laying arm with the mouthpiece at its end. Additional floats at the tip of the legs improve the list.

Hydraulically drive stilts provide stability during the laying operation.

Without moving the boat from one operating position up to 22 clay strips can be laid with a length of 20 m, width of 80 cm and thickness of 20 cm. This is accomplished by moving the carriage laterally and the bridge longitudinally. The thickness of the seal can be varied by changing the mouthpieces.

The clay laying boat and clay preparation boat can be coupled together at both sides so that the mixture can be transfered from either side. This is necessary because the operation requires that work be accomplished in both directions.

The boats are continuously connected with on another while

Fig. 9. Suction-cutter dredge in operation enlarging the canal cross section

Fig. 10. Laying boat

working on one sealing section and are moved from section to section as a unit. Other boats can pass from the working boats without interference.

The operations for lining a canal are as follows: After removal of the old lining, excavation of the bed and completion of the new profile under water the seal is installed in three strips in individual sections.

First a 17.60 m wide strip is laid on the bed at the foot of the bank with connection to the section completed. 20 operating positions of the laying bridge are required for an area of 350 m². After laying the center strip on the bed the boats move back. The laying boat is turned 180° and lays the bank strip. On the bank the individual strips are layed from bottom to top so that each strip of clay laid supports the next.

Then the bed strip next to the pile wall is closed. The lags of the laying boat, which is again turned 180°, slide along the pile wall during the laying work.

In this manner a closed, seamless carpet results over the entire width of the canal section for section.

The size of the working section is selected so that the area without lining or protective layer subjected to the attack of the propellers of the boats passing is as small as possible, but still just economical to line.

At the land station the natural clay brought by truck from the clay pit is cleaned of stones and other unusable constituents in the sieve kneader and pulverized. The cleaned clay material is loaded in buckets and transported to the preparation boat.

On the preparation boat the cable dredge loads the material into the box charging unit. From here it travels to an automatic weighing station where it is metered in precise quantities to the compulsory type mixer.

The mixer further pulverizes the clay, homogenizes it and prepares it to form a highly flexible mixture by adding water, cement and additives.

The mixture is then transported by an angular elevator to the supply hopper for the thick liquid pump, which pumps it to the laying ship at a pressure of approx. 100 bars.

On the laying boat the mixture travels through the laying arm pipe on the longitudinally mobile carriage to the mouthpiece on the end of the laying arm. The 20 m long strips are laid by moving the carriage longitudinally.

After laying one strip the entire bridge moves forward 80 cm in the lateral direction and the next strip is laid right next to the first without a joint. This results in a closed clay carpet without joints or cracks.

The stabilizing agent added to the mixture prevents erosion resulting from passing boats before the protective layer is installed.

Immediately after completion of one section the sealing layer is covered with a mineral filter and gravel in separate operations from two gravel boats, als developed by Holzmann.

The equipment present here can be used to install both types of seals without interrupting normal navigation.

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