Rehabilitation of gravity dams
At the example of Neunzehnhain II Dam

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ICOLD Annual Meeting in Dresden
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Wir planen das Ganze

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Neunzehnhain II dam

General Data

River Lautenbach

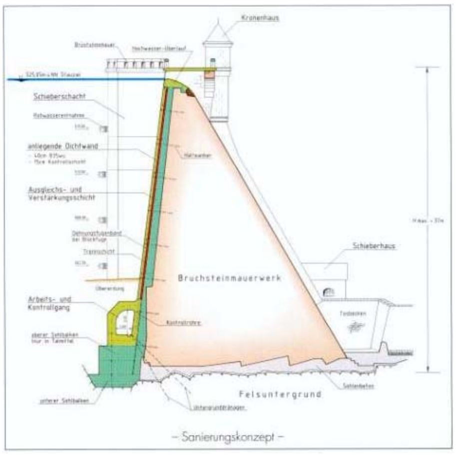
Nearest city Lengefeld (Erzgebirge)

Purpose
Supply of drinking water in joint operation with the lower-lying Neunzehnhain I dam

Dam type/sealing element
Masonry dam with curved axis, Intze typ

Construction period
1911 - 1914; 1996 - 2000 (rehabilitation)

Start of operation
1914; 2000 (rehabilitation)



Technical data

Hydrology

Catchment area	13.46	km^2
Mean annual discharge	5 2003 10^3	m^3

Reservoir

Maximum water level	525.32	m a sl
Normal water level	525.05	m a sl
Minimum operating water level	508.72	m a sl
Minimum water level	493.65	m a sl
Gross capacity	2 9733 10^3	m^3
Storage	2 8953 10^3	m^3
Effective storage		
Surcharge flood storage	783 10^3	m^3
Flood storage	0	m^3
Active storage	2 5953 10^3	m^3
Inactive storage	3003 10^3	m^3
Dead storage	0	m^3
Reservoir surface at maximum water level	3013 10^3	m^2
Storage capacity/Mean annual discharge	0.56	

Main dam

Height above lowest foundation	37.81	m
Height above valley bottom	33.00	m
Crest length	250.00	m
Crest width	4.90	m
Dam volume	51.63 10^3	m^3
Dam slope upstream face	1 : 0.11	
Dam slope downstream face	1 : 0.58	

Introduction

In Germany are numerous gravity dams, which were built at the turn of the century. These dams indicate numerous things in common:

- They are bricked from rubble masonry,
- they are founded in the rock,
- they have an arch-shaped ground plan,
- they are monolithically manufactured and have no transverse or block joints,
- they have a sealing plaster with a impervious layer on bitumen or tar base,
- their seal is protected by a blinding brickwork or a blinding concrete,
- seepage passing the sealing should be caught by wall drainage.

This construction was developed at the end of the last century by the pioneer of the German dam construction Professor Dr. Otto Intze. These dams are also called "INTZE-dams".

After 100 years of operation they indicate damage by aging, which must be repaired. In the following chapters the rehabilitation and the necessary preliminary works are described by the example of Neunzehnhain II Dam.

2. Actual condition before the rehabilitation

Construction

The Neunzehnhain II Dam is a dam for drinking water. It is situated in the Erzgebirge (ore mountains). Operator is the Landestalsperrenverwaltung (LTV) (dam authority of Saxony). The dam was built in the years 1911 to 1914. The dam is a gravity dam made of rubble masonry without transverse joints and with an arch-shaped ground plan (R ~ 226 m). The maximum height above ground level is approximately 38.0 m, the maximum base thickness is 25.4 m and the top width is 4.50 m. The dam is bent on the downstream face 1:0,574 and on the upstream face 1:0,118. The visible crest of dam is 253 m. The links between dam and valley slopes are over grounded.

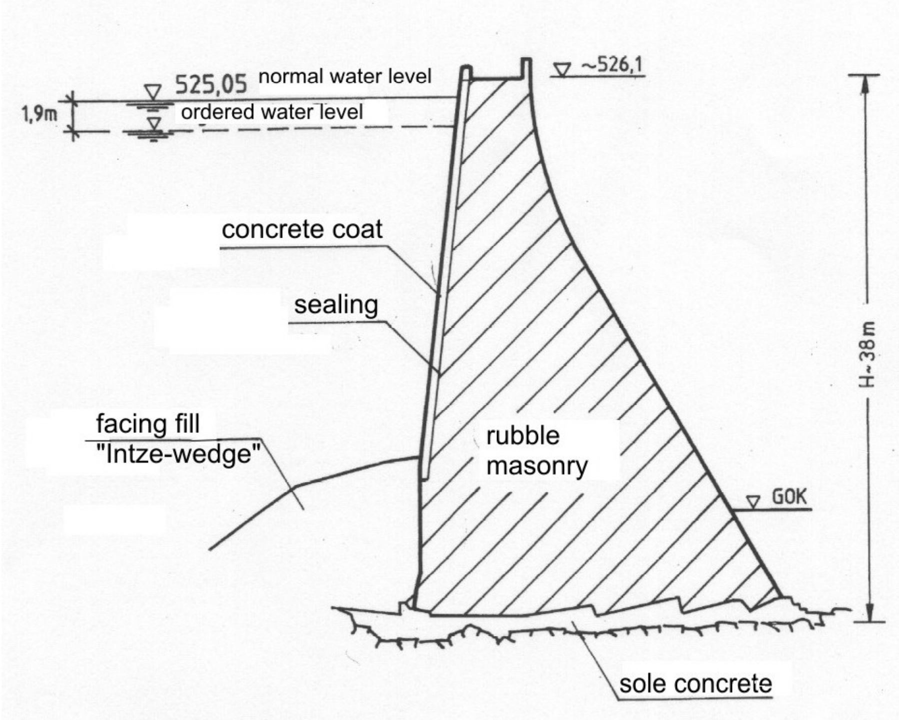


Fig. 1 Wall cross section before the rehabilitation

The natural stones of the core masonry are from biotite-schist, which are bricked in an irregular coursed masonry-work. The mortar consists of 1 percentage by volume cement, 0.3 percentages by volume lime, 0.5 percentages by volume trass and 4.8 percentages by volume sand.
The downstream face of dam consists also of mica schist rough stones. The upstream face is sealed against water with a sealing coat on a cement-trass-plaster.

From the bottom to 500.0 m a. s. l. the sealing is protected by a facing fill ("Intzekeil"="Intze-wedge"). This facing fill is sloped to the reservoir. Above the facing fill a concrete coat protects the sealing.
There is no dam drainage behind the sealing.
The building is founded on solid rock, on which a sole concrete with a tooth-like surface compensates unevenness.
In the foundation exists a dark mica schist of relatively even composition. The main quantities are quartz and biotite. The rock has a fine-grained-crystalline structure and is relatively solid and unweathered. The permeability is generally low.
The spillway is an uncontrolled overfall-spillway situated in the centre of dam; with nine bays of approximately 40 m total overflow length.
The outlet works are embedded in two tunnels situated in each case at the bottom of the valley slopes. The pipe diameter is DN 600.

Substance evaluation
We examined stability and adequacy of dam and foundation in the following work procedures:

1. analysing available documents
2. determining computational stability after the state of the art
3. exploring status and condition of the dam and the rock foundation (already 1983)
4. installation of uplift pressure measuring instruments
5. exploring and evaluating material parameters

In addition we evaluated the status and the configuration of operating equipment as well as the measuring and checking devices.

<u>To put the results together</u>:

- Stability cannot be proven - according to DIN 19702 for the loading condition: full reservoir. For that reason the reservoir level had to be drawn down 1,90 m.
- Under exceptional loading conditions the water level may rise up to 45 cm above spillway crest. For that loading condition stability cannot be proven.
- The dam condition can be described sufficiently, because material parameters could be derived sufficiently.
- At the time of dam construction uplift and joint water pressure was not considered sufficiently in the calculation. The " natural uplift pressure distribution " (I = 1.0) may not be reduced due to available measured values.
- The dam has no upstream drainage and no effective sealing any longer.
- Especially in the upper dam area the protective coat is not rehabilitable.
- The spillway including their spillway bridge (crest bridge) are in a extreme bad condition. A reconstruction of the concrete components is not possible due to alkali aggregate reaction (AAR) of the concrete.
- The dam crest and the crest covering are destroyed, so rainwater penetrates into the dam.
- The motion behaviour of the dam is interpretable during a longer period. There are anomalies. These are however interpretable.
- The core masonry is in a satisfying status. There are obviously no structure of zoning and no by quality differences or by overstressing developed inhomogeneous areas (except within the crest area), so that a linear tension distribution is valid.
- The rock foundation area beneath a thin weathered zone is predominantly solid. Considerable waterways are expected only within the foundation area.
- Configuration and status of operating equipment and the measuring and checking devices do not correspond to the state of the art.

Requirement for reconstruction
The reconstruction of the dam was necessary, because

- stability - with the necessary distance to safety - can not be proven by calculations
- no relief parameters for the stability proofs were determined or can be expected
- the condition of substantial components, especially the upstream sealing, is extremely bad
- the usability of the masonry can not be ensured for the future, because of the continuing seepage
- at least the dam has to be operated in accordance with the generally recognized rules of the technique or has to be adapted to the state of the art (§ 85 exp. 2 and 3 SaechsWG).

3. Variants of rehabilitation

Planning objectives
The variants are developed after two planning objectives:

1 re-establishment of calculated dam stability
The dam rehabilitation is carried out only with regard to current (momentary) stability. Dam and foundation remain further more or less strongly flowed through. The fabric of the dam remains further unprotected. The effect of the rehabilitation will last only some years or few decades.

2 re-creation of computational stability and the adequacy
A flow through the dam and foundation is prevented or limited. Thus the fabric of the dam is protected to a large extent against further corrosion and erosion processes. The effect of such rehabilitation will extend the adequacy by another 80 - 100 years.

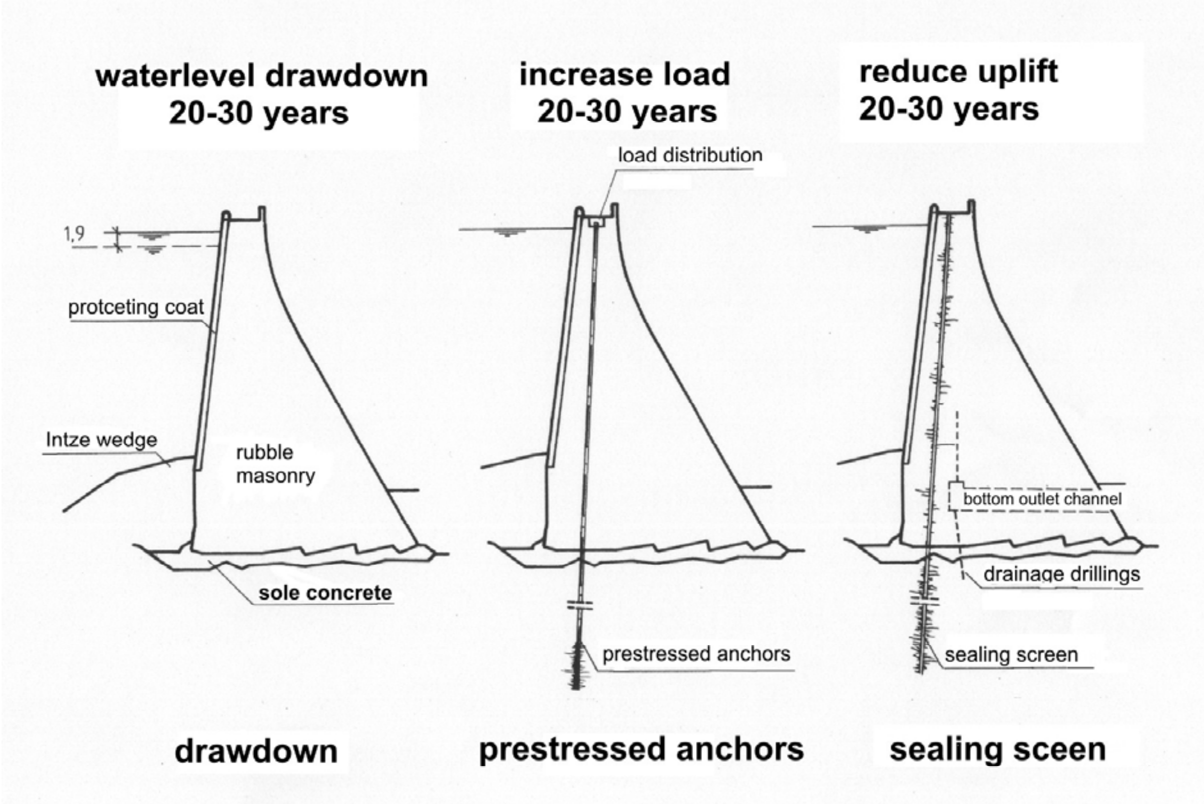


Fig. 2: Variants of rehabilitation

- Possible variants of rehabilitation show fig. 2. These are analysed in an evaluation matrix. The criterions of evaluation are divided into final state and construction status.

Evaluation of variants

Final state

-Scope of rehabilitation
Evaluation of the scope of rehabilitation at the dam.
Basic question: How many or few components will be repaired or renewed?

-Stability
Evaluation of achieved safety.
Basic question: Do exist static reserves?

-Bearing system
Evaluation of the intervention on the " original " bearing system by the rehabilitation.
Basic question: Will the bearing system changed unfavourably?

-Continuous useability/adequacy
Evaluation of the protection of the fabric of dam by the type of rehabilitation.
Basic question: When is the next rehabilitation necessary?

-Duration of service
Evaluation of the normative duration of service life of the rehabilitated dam.
Basic question: When is the next rehabilitation necessary?
-Purpose of service
Evaluation of the reservoirs storage volume.
Basic question: Is a water level draw down necessary after termination of the rehabilitation?
-Operating equipment
Evaluation of the range of the rehabilitation at the withdrawal system, bottom outlets and raw water withdrawal.
Basic question: Are all components of the withdrawal system adapted to the state of the art? How is the raw water withdrawal?
-Scrutiny
Evaluation of the scrutiny of a sealing or the rehabilitation method and the personnel expenditure for the check.
Basic question: How can lacks or damages to the rehabilitation and to the dam be detected?
-Restorability
Evaluation of the opportunity of recreating or repairing of rehabilitation and elements of rehabilitation in the case of damage.
Basic question: Under which technical and financial expenditure can damage be corrected?
-Sensitivity
Evaluation of the sensitivity of the type of rehabilitation to external influences e.g. vandalism.
Basic question: Does the rehabilitation element have to be protected from external influence?
-Maintenance expenditure
Evaluation of the expenditure for maintenance during the service life.
Basic question: Does the type of rehabilitation have to be maintained beyond the " normal " maintenance?
-Protection of monuments
Evaluation of the interests of the protection of monuments.
Basic question: Is the dam appearance changed? The conservation of the fabric of the dam and thus the conservation as monument are evaluated with the criterion " continuous usability ".

Construction status
-Technical risks
Evaluation whether the execution holds technical risks or not.
Basic question: Is the type of rehabilitation among comparable boundary conditions established?

-Ecological effect
Evaluation whether the rehabilitation concerns ecological interests or not.
Basic question: At which storage volume and reservoir level is it possible to rehabilitate and how long will the rehabilitation last?
-Back-up water supply
Evaluation whether a back-up water supply is necessary or not.
Basic question: At which storage volume and reservoir level is it possible to rehabilitate and how long will the rehabilitation last? Are there supplying alternatives?
-Risk of costs
Evaluation of the risks by the work on the stock.
Basic question: How sensitive is the type of rehabilitation in the case of " surprises " at the existing dam?

After an evaluation matrix, in which value numbers were assigned to the aforementioned criteria, a rehabilitation with a reinforced concrete sealing resulted as the technically and economically most acceptable solution. Before the final technical execution was determined, also for this solution variants were developed and evaluated cost-related. Fig. 3. shows the variants.

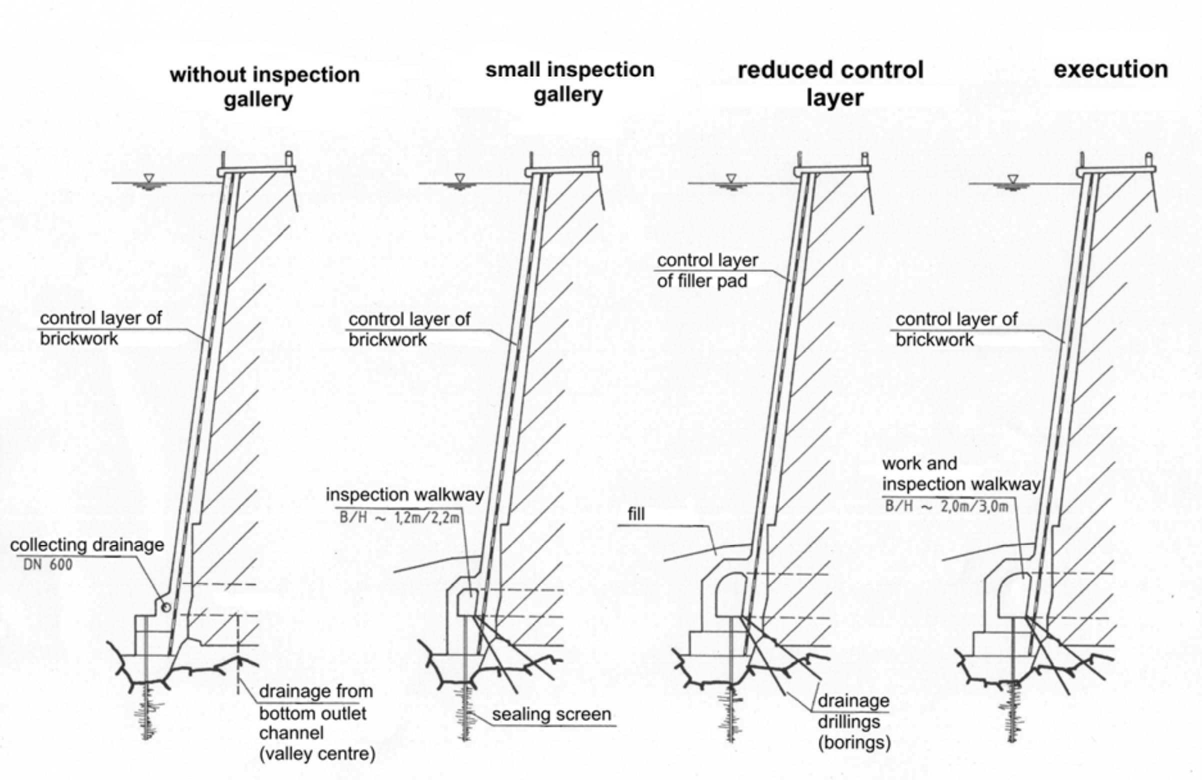


Fig. 3 Variants of reinforced concrete sealings

At the end a variant with a control layer from brickwork and an optimally dimensioned work and inspection gallery was selected.

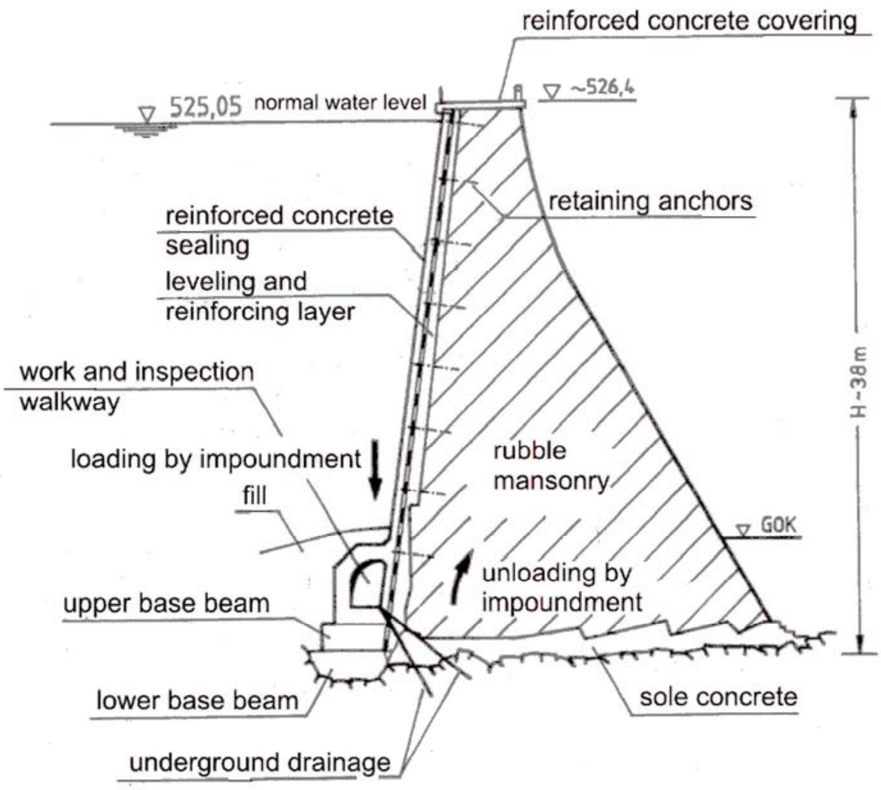


Fig. 4 Wall cross section after the rehabilitation with reinforced concrete sealing

4. Rehabilitation construction

The design features of the reinforced concrete sealing are:

<u>Foundation and base beam</u>
The upstream sealing merges 1 m deeper into the rock than the existing rubble masonry. Thus waterways close to the foundation in the explored loosening zone are to be detected and stopped. The excavation began in sectors at the valley slope, carefully and without blowing up or tearing. It was not allowed to undermine the old dam. In the case of deeper excavations or unsteadiness larger freestanding surfaces were secured by spraying concrete and rock nails. Deeper excavations or unsteadiness in the new foundation bed are compensated by a joint less concrete beam ("lower base beam"). This concrete beam has a reinforced sealing zone at the upstream side, although it should be only a " rock back-up ". The first 30 cm of the concrete beam were poured immediately after the geological acceptance, to prevent a long term uncovering of rock.
The work and inspection gallery drains to the downstream face. Therefore the sole of the gallery is in valley centre on the level of the bottom outlet tunnels.
A so-called „upper base beam“ compensates the difference in altitude to the lower base beam. This beam has no expansion joints.

Compensating and reinforcing layer

According to the static calculation (FE 2D) the bearing dam cross section at the valley floor had to be strengthened approximately 1.85 m and at the crest of dam approximately 0.2 m. The reinforcement consists of an unreinforced concrete (B 15), which may tear and thus receives a similar elastic modulus as the masonry.
The concrete dam has an arch-shaped ground plan, the later pre-to reinforced concrete sealing fields have to be even. Thus the upstream reinforcing layer - like the reinforced concrete sealing - is polygonal.
Reinforcing layer and existing dam have to form a static unit. The upstream concrete coat was not interlocked with the core masonry, it had to be aborted and be replaced by concrete (B 15). For the transmission of thrust forces the old bitumen based seal finery had to be removed and disposed. The reinforcement and the existing dam are needled by retaining anchors. It prevents shrinkage of the green concrete toward the upstream face, to the concreted mass centre of gravity.
The combination of old masonry and new components can be supervised from the inspection gallery by accessible niches. Into these niches drains also a longitudinal drainage that intercepts seepage, which rises in the joint between old dam and reinforcement or in the old masonry.

Separation layer

On the entire height of dam a separation layer is stuck on the reinforcement layer. The separation layer enables movements between the reinforced concrete sealing and the bearing masonry. The separation layer is long-term stable and long term plastic. It is from a 5 mm thick elastomere bitumen-welding layer, which stuck joint less together by hot bitumen.

Work and inspection gallery

A work and inspection gallery is at the reinforced concrete sealing bottom. It is not stiff connected with the dam - like the reinforced concrete sealing. By this construction a loading and no unloading in the case of a completely impounded reservoir is ensured.
The gallery is made of watertight reinforced concrete (B 35 wu) with block lengths of approximately 8.50 m in average. The block joints are sealed by expansion water bars from a combination polymer (PVC P/NBR).
The gallery size allows the execution of drilling and injecting work for an upstream foundation sealing and a drainage fan lying behind. The inspection gallery is accessible by the two bottom outlet tunnels from the valley. The old upstream plugs of the lugs were already removed at the beginning of the construction period, in order to lead the water alternately through the tunnels.
Beyond that the inspection gallery is also accessible from the two slopes (escape route). In each case approximately 5 m before the visible wall end a broad slot (2.5 m) from the crown is broken into the dam.

The slot was concreted, the ceiling as a vault. In the sole stairs are formed. Thus the " defect-area " in the dam is compensated again. The downstream dam entry is adapted to the historical appearance of the dam. The work was executed in the winter term, because then the wall is not under temperature-related pressure.

Controllable reinforced concrete sealing
The reinforced concrete sealing begins above the inspection gallery. It is divided into single disks, which reach up to the crest of dam. The material is also watertight reinforced concrete (B 35 wu). As the inspection gallery the disks have a width of approximately 8.50 m on the average and are connected by expansion water bars from PVC P/NBR. Expansion and construction joints form a closed system.

Behind the not permeable wall a layer of filter stones (control layer), which is shear resistant, is connected with the reinforced concrete sealing. This filter layer consists of frost resistant brick layer stones DIN 105 VHLZ 2 DF (vertically perforated brick), 11.5 cm thick with 3.5 cm thick mortar joint (MG III) towards the separation layer. When the reservoir is impounded the reinforced concrete sealing is controllable on defects by the vertically perforated bricks.
With vertical distances from approximately 4.0 m, in the control layer slightly inclined collecting channels are attached, always below the construction joints of the reinforced concrete sealing. The collecting channels flow into vertical control pipes (PVC drainpipe DN 100). The distance of the control pipes is approximately 2.5 m. The pipes are led up to the crest of dam and have a watertight cap. The control pipes are straight-line. It is easier for control and maintenance. At the toe of dam the control pipes lead over vertical plugs or niches into the inspection gallery. Every 14 m^2 retaining anchors with a diameter of 40 mm are between the reinforced concrete sealing and the old dam. The retaining anchors were dimensioned as formwork ties and embodied in the old masonry 1.4 m deep. During operation the anchors have to protect the reinforced concrete sealing against (temperature related) arching above the different water levels. Additionally they prevent a buckling of the reinforced concrete sealing from dead weight.
The anchors do not obstruct the movements of the reinforced concrete sealing parallel to the separation layer. In the upper third of the reinforced concrete sealing fixed points prevent an emigrating in horizontal direction, permit however movements in vertical direction.

Slope connections
The inspection gallery ends with the slope-side accesses. Above these accesses slope connections are manufactured according to the principle of the reinforced concrete sealing. After a watertight concrete a control layer is right behind attached to the old dam. This control layer drains at the sole over an U-shaped gutter stone into the inspection gallery.

Crest of dam
The crest of dam had to be sealed. Because of the reinforced concrete sealing porch it is approx. 80 cm thicker than before. The entire width of the crest is covered with watertight reinforced concrete, in a construction height of on the average approximately 35 cm. In order to minimize costs for demolition and to increase the freeboard, the crest of dam next to the spillway was increased by approximately 30 cm (on upstream elevation 526.31 m a sl). This height corresponds to the old height of crest within the spillway area, so that the ramps beside the spillway are not longer necessary.
The reinforced concrete cover is divided into single areas. These are connected with expansion water bars of the same material as used in the reinforced concrete sealing.

Underground grouting
Waterways within the area close to foundation were interrupted by the integration of the inspection gallery (or base beam), already described, into the rock. A sealing screen usually seals the „deeper“ underground. Due to good geological conditions and the construction of the inspection gallery (increase of the contact pressure with rising water level) no sealing screen is necessary.

Underground drainage
Independently of the requirement of a sealing screen the underground behind the sealing level had to be drained, in order to fulfil the static boundary conditions (I = 0.6) safely. For that reason drainage borings are drilled from the inspection gallery deeply into the underground rock (2 to 3 m) with a distance of 2 to 3 m, under an angle of 10 to 20°. Under the present geological conditions a danger of cleft flushing does not exist.
In the case of leaching or sintering sealing screen and drainage can be manufactured or re-created or strengthened after years of the operation at justifiable expenditure without interruption of the dam operation from the sufficiently dimensioned inspection gallery (Fig 5).

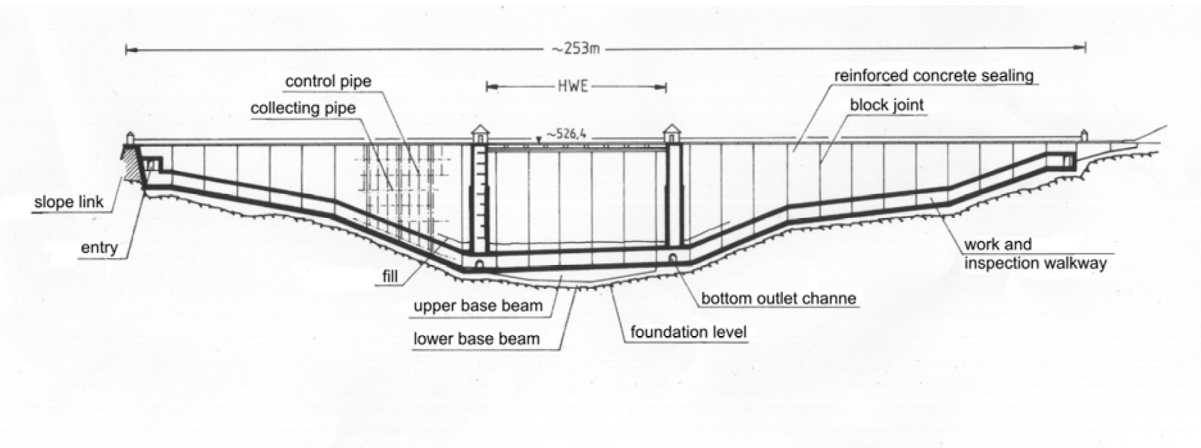


Fig. 5 View of diaphragm wall with section through inspection gallery

5. Re-commissioning

At the beginning of 1996 the reservoir operation was stopped. The construction work began in June 1996. In November 1999 the essential works were finished, so on 23.11.1999 the test impoundment could begin. The maximum water level was achieved on 03.04.2001. Fig. 5 shows a downstream view of dam with the overflowing spillway. All measurements and observations of the dam during test impoundment confirm the success of the rehabilitation works. Both the measured deformations and the drainage performance from the - unsealed - underground are in the range of the prognosticated expectancy values.

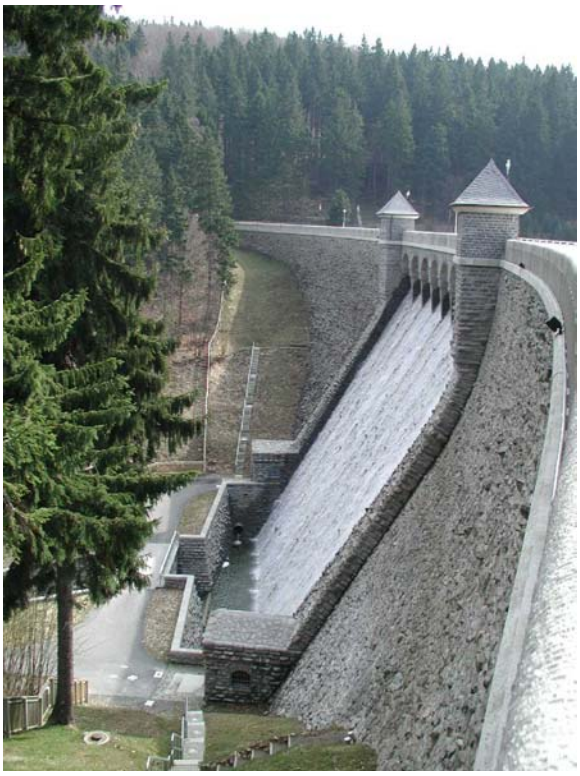


Fig. 6 Downstream view with spillway

It remains recapitulatory stating that all work meets the high technical claim of quality. Further it succeeded to adapt those almost 90 years old dam to the state of the art and emphasizing the peculiarity and the beauty of the old dam again.

6. Keywords

Gravity dams
INTZE-Type
Rehabilitation of dams
Reinforced concrete sealing
Historical dams

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