Rehabilitation of the Sylvenstein Dam, Germany Success Proof by Major Flood 2013

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Abstract

Preventing flood damages is a central role of dikes and dams. The Sylvenstein Dam designed to manage the water level in the Isar River by mitigating flood damages downstream, for adequate low-tide-heightening of the river for better navigability and to generate electrical energy was built in the south of Germany in the 1950ies.

The Dam, with some upgrades over the years, performed very well its designated purposes. Preparing for presumed increasing flood events due to the climate change with higher and sudden precipitation, a restoration design for the Sylvenstein Dam was implemented between 2012 and 2014. The significant renovation part was the installation of a plastic concrete cut-off wall through the embankment dam core and into the alluvium filling the gorge created by the Isar River. In 2012, the wall was executed and completed. The Reservoir was partly impounded during the installation of the new barrier wall.

During heavy rainfalls in 2013, due to the flood retention capacity of the Sylvenstein reservoir, the peak discharge of the Isar River into the city of Munich could be significantly reduced thus no significant damage could be observed along the Isar River. Due to the new cut-off wall, it was possible to store a maximum of water for a longer period reducing the outflow from the dam essentially over the critical time-period, necessary, as dikes along the Danube were heavily burdened and even broke in two areas.

Keywords: Sylvenstein Dam, Dam Upgrading, Dam Rehabilitation, Plastic Concrete, Concrete Cut-off Wall.

1. INTRODUCTION

The Sylvenstein Reservoir was built between 1954 and 1959. For its reconditioning after 50 years of operation, it has been planned to strengthen the dam core by means of a deep concrete cut-off wall (COW) and to equip the dam with a state-of-the-art water collection system and a monitoring system for water seepage.

In this context, the Bavarian Ministry of Environment via its Bavarian State Office for Water Management in Weilheim (WWA-WM), the local Water Board, has entrusted Bauer with the construction of the 70 m deep and 1 m thick diaphragm wall forming the new seepage barrier in the embankment dam. The reservoir was originally meant for water augmentation to regulate the minimum low water flow of the Isar River. Meanwhile it has to deal with detention of water during flood seasons protecting the area of the city Bad Tölz and of Greater Munich from devastating floods like the one in 1999 and 2005. Furthermore, the refitting of the reservoir has to allow for prevention measures in case of climate changes.

The 42 m high and 180 m long earthen embankment dam is underlain by a 100 m deep gully formed into dolomite and filled by alluvial river sediments, which made it necessary during dam construction to perform grouting works to create a multi-layered sealing curtain of clay-cement grout.

The watertight thin core of the dam built in the early 50ties consists of a mix of gravel, fine sand, silt and bentonite sandwiched between filters of moraine gravel from both downstream and upstream sides.

The refit-design asked for a new sealing element by means of a 2-phase cut-off wall which had to be constructed as compensation to the core of the dam slightly towards the downstream side and had to key in to the steep rock flanks. The depth of the cut-off wall has been determined based on reconnaissance drillings performed down to 140 m deep in the substratum of the dam. Due to imbedded layers of gravel and rock sediments and to the fluctuating permeability in the bottom sealing, the cut-off wall had to be extended down to 70m below the dam crest (suffusion stability).

The 10,000 m² cut-off wall was constructed by Bauer Spezialtiefbau from dam crest which is stretching over 180 m. The edges of the wall had to be embedded in very hard rock. Particularly challenging was the timely execution from a restricted working platform width.

Due to the topography of the site and the restricted working space at the dam crest, logistic challenges had to be dealt with; concrete batching plants were installed downstream in the valley below the embankment dam and the plastic concrete had to be pumped 50 m upwards. Moreover, the traffic on the adjacent scenic road could be kept up by means of a temporary road over the dam in direction towards the Achenpass, Austria.

2. FUNCTION OF THE EMBANKMENT DAM – REASONS FOR THE STRENGTHENING

The Sylvenstein Dam is the oldest water reservoir in the State of Bavaria. It has demonstrated its protective function during several floods at the rivers Isar, Dürrach and Walchen for the downstream communities and of the State Capital Munich.

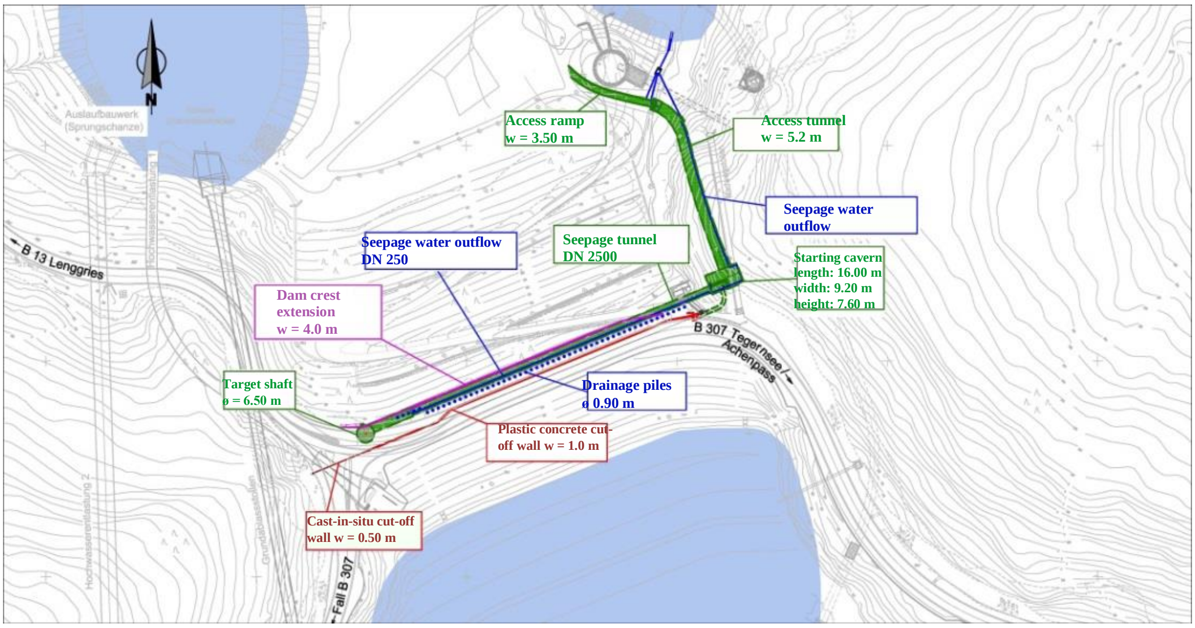

Figure 1. Layout of the rehabilitation concept (Source: WWA-WM)

Reasons for actual reconditioning of the sealing system were predominantly to improve the structure of dam and foundation; to strengthen the 50-year-old slim core; to install a new positive watertight sealing in the embankment dam. To achieve the targeted reconditioning, a design was awarded to CDM Smith Consult GmbH.

The designed plastic concrete cut-off wall has the functions: a) sealing the embankment dam, improving the existent aging core and b) sealing the underground structure to a designed depth of approx. 70 m below dam crest. Further a seepage collection tunnel and drainage piles downstream of the cut-off wall and a new seepage water measuring instrumentation was installed.

The following steps were essential to ensure long lasting functionality of the Sylvenstein dam:

The depth of the COW had to be designed in such a way that no damage will be caused by seepage in the substratum below the COW and that the assured embedment into the existing rock and concrete structure along the abutments of the embankment dam had to be watertight.

The presetting of the design asked for a two-phase diaphragm wall with a wall-thickness of 1 m; the material of the new barrier wall had to be plastic concrete assuring a permeability not exceed 1 x 10-9 m/s in the laboratory with a nominal tensile strength of 500 kN/m² and a maximum stiffness of 450 MN/m².

3. CUT-OFF WALL CHARACTERISTICS; CONSTRUCTION PROCESS; TECHNICAL FEASIBILITY

The new cut-off wall is required to seal the dam and the subsoil below to a defined depth. It was designed to implement a plastic or clay concrete cut-off wall which consists of natural aggregates without the use of artificial sealing material and additives. In order to guarantee the planned permeability of kf < 10^{-9} m/s full-face, a diaphragm wall of 1 m thickness was executed ensuring the designed continuity of the sealing system. In order to fully seal both the dam core and the subsoil, a tight embedment into the lateral sloped rock faces had to be implemented. For this reason, the use of a hydro-cutter was chosen. As a result of the expected long excavation periods of the individual diaphragm wall elements, the need to cut through boulders and into the sloped rock flanks, only the two-phase diaphragm wall system was feasible.

For the designed depth of the cut-off wall, it is decisive that there is no suffusion in the subsoil. A depth of 70 m was specified after having calculated the stability to suffusion and considering the soil analysis as interpreted by professional engineers. The new cut-off wall was to be embedded into the existing sealing blanket. In the original construction phase, some steel grout pipes remained in the subsoil. They posed a critical obstruction during the cut-off wall installation using a hydro-cutter. Therefore, in plan-view the cut-off wall was positioned downstream adjacent to the grout curtain. The old sealing core in the dam remains therefore largely untouched and effective. The dam crest had to be widened by 4.5 m to provide a sufficient working platform for the main equipment. However, it was only possible to operate the hydro-cutter equipment straddling across the wall axis parallel to the dam axis.

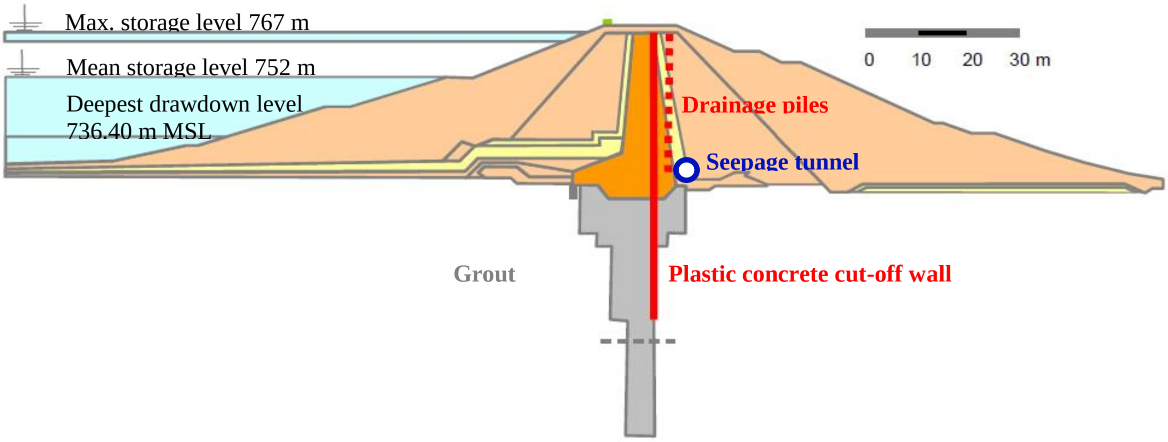

Figure 2. Standard cross section with cut-off wall, drainage piles and seepage tunnel

4. Construction of the Cut-off Wall

The diaphragm wall method has been proven for decades as the system to install concrete cut-off walls to greater depths. Grabs and hydro-cutters are being used with slurry supporting excavations, safely and successfully to remediate impounded embankment dams. Typically, clay concrete – so called plastic concrete – is chosen to install the durable and elastic seepage barrier.

For the Sylvenstein dam, on a limited working space, a hydraulic grab and the specially modified hydraulic cutter was chosen to install the wall to the satisfaction of the client, both in time and budget. The required slurry handling plant – consisting of mixing, storage and desanding units – had to be installed along the road to the dam crest. The concrete batching plant was placed downstream of the dam.

Pre-excavation with a grab is the method typically used for economic excavation of the panel elements in soil where depths usually do not exceed 40 m. The hydro-cutter technology is the established and tested method for cutting into rock and through boulders, ensuring a defined overlap between the individual panels for a continuous wall and for installing deep vertical panel elements.

Figure 3. Cut-off wall equipment on a limited working platform

The diaphragm wall executed at the Sylvenstein Dam had to reach a maximum depth of approximately 70 m below the dam crest as there are alternating layers of gravel and rock sediments and the highly varying permeability of the old underground sealing. Preparation works were executed with a grab in the upper part of the trench. Then, the diaphragm wall was installed, deploying a Bauer BC 40 Trench Cutter with a Bauer MC 128 base carrier. The wall is laterally embedded in very hard dolomitic limestone.

The location and natural surroundings of the project site were a challenge to logistics. As working space was limited on the dam crest the concrete mixing plant was assembled in the valley below the dam and the plastic concrete was pumped up 50 m to the work platform.

The mix design for the plastic concrete (clay concrete) was developed by the Technical University of Munich and conforms to the DIN EN 1538 standard. A permeability of $k_f < 10^{-9}$ m/s at a low stiffness was specified.

Table 1- Project specific mix design for plastic concrete / Clay concrete

Mix No.	H_2O (kg/m³)	Binding agent (kg/m³)	Clay powder (kg/m³)	Gravel (kg/m³)	Sand (kg/m³)	Retarder [%]	Plasticizer [%]
H 0.57	375	125	220	521	782	4	1,5

The quality was assured through an intensive testing and control regime, all of which was defined by the Contractor in the project specific Quality Management Plan for approval by the Engineer.

5. CONSTRUCTION OF THE SEEPAGE TUNNEL SYSTEM AND COLLECTION PILES

Construction of the tunnel system started in May 2013. Firstly, the access tunnel and the starting cavern were driven by drilling and blasting and the target shaft was executed. The concrete pipes with a length of 2.8 m each were installed using a tunnelling machine with slurry supported working face. As the concrete cut-off wall was installed already, it was not necessary to lower the lake water level. The performance for the concrete pipe advancement was up to 5 pipes/24hours. The target cavern was reached with a deviation of less than 3 cm after 16 days. In 2014, the drainage piles are being constructed and connected to the tunnel by horizontal drills. Subsequently, the tunnel will be extended and the site instrumentation installed.

The rehabilitation package was started in 2011 and is planned to be completed by 2015. The total budget amounts to 24 million € and the costs will be shared equally by the Free State of Bavaria, Germany and the European Regional Development Fund (ERDF).

During the entire construction period the Sylvenstein Dam has to fulfil its core tasks which are flood protection and heightening of low water of the Isar River. Therefore, the reservoir was always partially impounded.

Figure 4. Cut-off wall installations with diaphragm wall grab, cutter and plants

6. FLOOD IN BAVARIA, GERMANY IN JUNE 2013

End of May 2013, with remarkably cool temperatures and constant rainfall, extensive heavy precipitation started, resulting in massive flood discharges and large scale flooding in Bavaria. Especially from May 30th to June 3rd the water levels reached record heights in many places resulting in catastrophic impacts in some areas. In the city of Passau, a new record height of almost 13 m above average was measured at the gauge Passau/Danube in the evening of June 3rd, (around 70 cm higher than during the Danube flood in 1954 - approx. 12.20 m), the highest Danube flood in the 20th century. This even exceeded the water levels of the highest known flood in the year 1501.

In Bavaria, the flood event caused damages amounting to about 1.3 Bio. Euro. The "disastrous flood" of 2013 once again drew the public's and media's attention to the flood issue. Apart from the enormous material damages, which considerably affected many citizens, Bavaria survived the flood relatively lightly. No loss of life was reported. The steps already taken within the scope of the flood protection programme 2020 for flood protection and risk management have proven effective and prevented more serious damage.

After the major flood events in May 1999 and August 2005, the June flood 2013 is already the third most significant event within the Isar catchment area, which severely strained the Sylvenstein Dam.

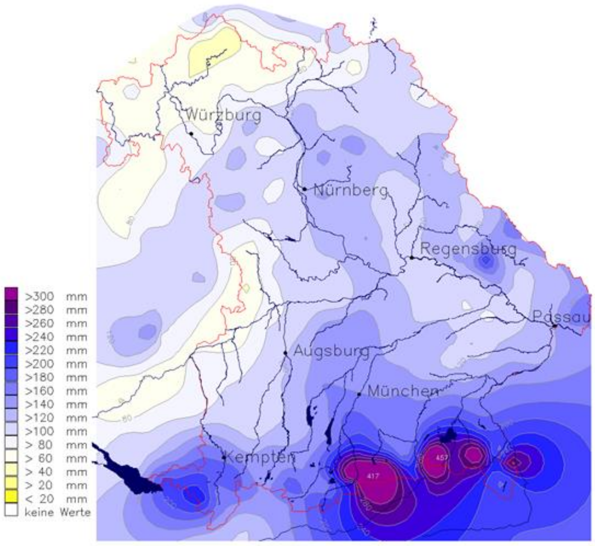

Figure 5. Precipitation volume of 26 May 2013 to 3 June 2013 in Bavaria

Other than at previous major floods during which mainly the discharge possibilities of the Alps and its edges contributed to the total flood runoff, here the complete Isar catchment area had rather uniform rainfall. Such rainfall could not be discharged in total in the Alps because the snow line during the flood was at approx. 1,800 m MSL. As the flood lasted so long, also the smaller Isar inflows contributed decisively to the flood peak. Thus, the return period of the Isar flood events increased downstream, starting near Munich.

The HQ-10 to HQ-20 inflow rate into the Sylvenstein Dam could be reduced downstream of the reservoir to an approximately HQ-10 inflow rate. Due to the enormous volume of inflow from the river Loisach (HQ-20), the river Amper (HQ-20 to HQ-50) and the massive rainfall on the interim area, the return periods starting from Munich increased. Below the inflow from the river Amper the return period was approximately at a HQ-100 level.

7. OPERATING THE SYLVENSTEIN DAM DURING THE 2013 FLOOD EVENT

The Sylvenstein Dam was hit by three inflow waves during the massive June 2013 flood. The first peak arrived at the reservoir in the morning of June 1st with about 300 m³/sec. The following day, the second wave reached the dam with approx. 550 m³/sec. After a very short subsiding phase (approx. ½ day) the highest inflow volume came with approx. 675 m³/sec; this figure corresponds near to that experienced every 20 years (HQ-20). On June 3rd, 99.7 % of the controllable water retention space of the Sylvenstein Dam was filled.

The old flood relief of the Sylvenstein dam became operational for the first time after its installation in 1954 from June 3rd to 4th. The volume of the flood event amounted to around 100 million m³ and thus exceeded the flood of 2005. Approximately 61 million m³ were retained, which is about 60 % of the total inflow waves. This is an excellent outcome in view of the extent and the duration of the flood wave; the standard floodwater retention space was used to almost full capacity.

It was only possible to manage floods such as in 1999, 2005 and 2013 by the dam rehabilitation measures taken from 1997 to 2001 (mainly by the construction of the second flood relief plant and by elevating the dam by 3 m). The current rehabilitation had set an essential milestone when installing the deep plastic concrete cut-off wall in 2012. Thus, due to the assured dam tightness after installing the new cut-off wall, it was possible to increase the impounded reservoir level to a record height and to keep it for an extraordinarily long time in order to drastically reduce the outflow considering the flood situation in lower lying areas.

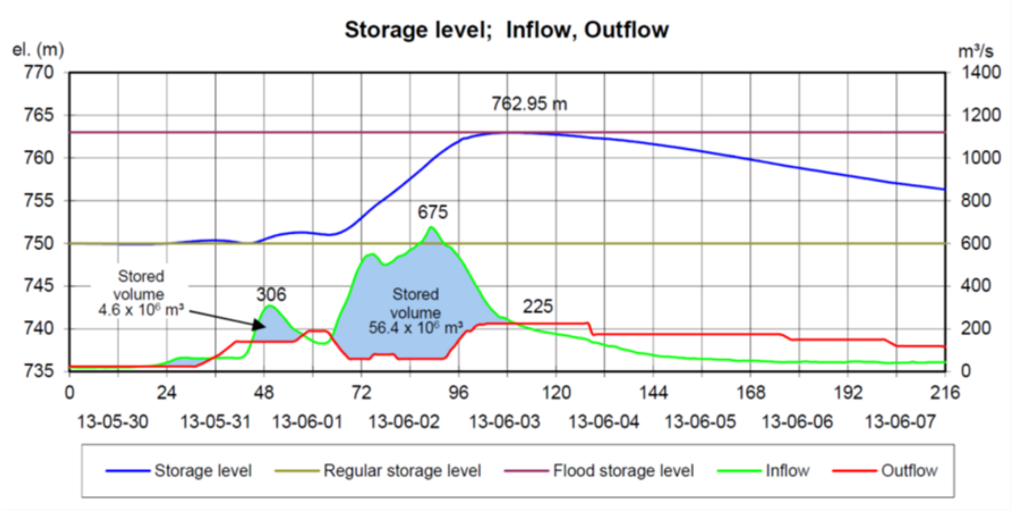

Figure 6. Storage management at Sylvenstein reservoir June 2013

At the dam itself, there was no major damage identified. However, the auxiliary dam (forebay reservoir) and the main reservoir had to be cleared of driftwood. During the flood the auxiliary dams retaining the bed-load again proved to work effectively. On the area with normal stored-up water level an echo sounder was used during a lake excursion. For the first time since the initial operation of the dam, the crest was measured during a flood. Although the reservoirs were completely filled, deviations of only a few millimetres were observed. The construction works (blasting) for the new seepage tunnel were interrupted for 10 days as a precautionary measure due to the full reservoirs at the Sylvenstein Dam.

8. CONCLUSIONS

The timing of the rehabilitation measures at the Sylvenstein Dam which started in 2011 was extremely opportune considering the flood of June 2013 because the centrepiece, (the installation of a diaphragm cut-off wall being up to 70 m deep in the dam core), was already successfully completed in 2012. Thus, the Sylvenstein Dam was capable of operating to its full potential. After the heightening of the dam in 1999, the financial means used for the Sylvenstein Dam again proved a resourceful investment considering the enormous damages which can be prevented in the complete Isar valley down to the city of Munich as well as the possibilities for relieving the water situation up to the Danube River.

9. ACKNOWLEDGMENT

The constructive and goal-focused cooperation between all parties involved including the head of the Water board, Weilheim, Germany Dr. Tobias Lang led to the successful completion of the plastic concrete cut-off wall in time. Tobias Lang and his team contributed as well in a significant way to the documentation of these works and the dam behaviour during the flood event 2013.

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