Eder Dam, stabilisation by permanent rock anchors- Monitoring and long term performance

Dipl.-Ing. Klaus Dietz, Stump Spezialtiefbau GmbH, Langenfeld
Dr. Wolfgang Habel, BAM, Berlin
Dipl.-Ing. Ingo Feddersen, BAW, Karlsruhe

1. Introduction

The Eder Dam was built in the beginning of the last century. In 1992/93 104 permanent rock anchors with working loads of 4500 kN were installed to improve the dam stability up to today`s technical standard. For the first time in Germany such high anchor loads were used. Referring to this a detailed measuring program, with anchor force-gauges and a fiber optic sensor system to monitor the fixed anchor length, was equipped.

The fiber optic sensor system gives for the first time the possibility to measure permanent the distribution of the anchor force directly in the fixed anchor length. The report informs about the results of 7 years monitoring and experience with the innovative fibre optic measurement system. The values of the sensors are compared with results of lift-off tests and anchor gauges. Up to now all systems work without any problems.


pic. 1. Eder Dam overview

2. Eder Dam

The Eder concrete dam (pic. 1) is a curved gravity dam with a radius of r=500 m. It is approx. 47 m high, has a floor length of 270 m and a crest length of 400 m. The concrete was constructed in greywacke-rubble masonry between 1908 and 1914, involving a total cost of 25 million Goldmark. The dam foundation consits of 50% undercarboniferous clay slate and 50% greywacke. Lake Eder has a length of 27 km and a storage capacity of 202 million m³. The storage reservoir serves various purposes: to increase the Upper Weser low water level, as flood protection and for energy production (Hemfurth Power Station 1). Tourism is also an increasingly significant factor.

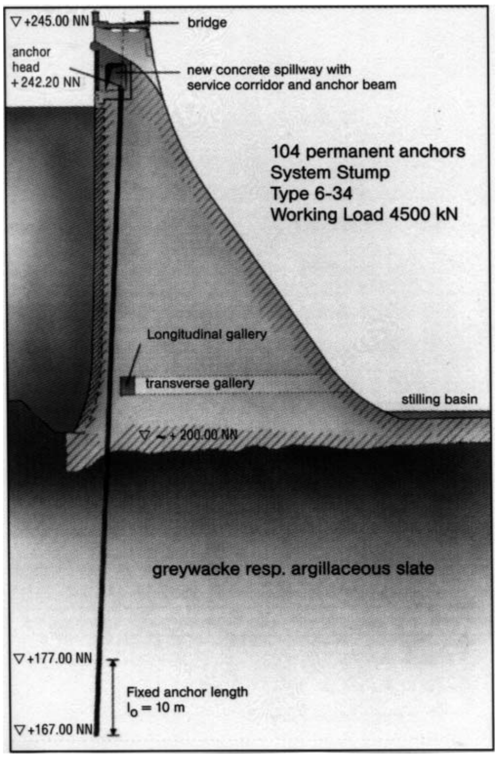
3. Rehabilitation Concept

Investigations carried out on the structure showed the structure's overall stability adversely affected by the occurrence of seepage in the bottom area of the concrete dam and an increase in bearing pressure resulting here from. Prior to its rehabilitation, the dam could therefore only be impounded up to 1,50 m below maximum pondage.

In addition, it was required that the dam be such that a one thousandyear flood (1100 m³/sec) be discharged via he flood relief. Originally, a discharge of not more than 750 m^3/sec had been foreseen, representing a one-hundred-year flood.

Comprehensive structural tests showed that a weight deficit of 2000 kN per lineal dam metre had to be offfset. The following alternatives were found suitable for execution on this project:

1. Anchor-fixing the concrete dam to the rock massif using permanent anchors (pic. 2).
2. Strengthening the concrete dam by application of a greater loads.
3. Sealing the concrete dam using face concrete formwork.
4. Support measures on the back side of concrete dam.



pic. 2: Cross section Eder Dam

For economic reasons and for the interest of both tourism, conservation and fishery (complete draw down of the reservoir not being required) and with due consideration given to the preservation of historical sites (conservation of the external appearance of the dam in its original condition) alternative 1 was chosen for the rehabilitation works. The dam crest was partially removed and replaced by a reinforced concrete load distribution beam evenly transferring the loads of the 104 permanent rock anchors, 4500 kN each, to the entire structure. Both load distribution beam and bridge were finally faced with the original masonry.

4. Drilling and Injection Operations

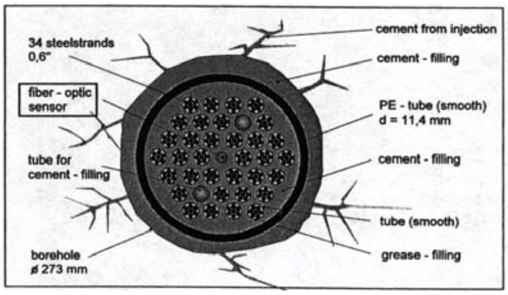
The 68 and 73 m deep boreholes produced for the later installation of the anchors had an inclination of 3.2°. Owing to the concrete dam's curvature, each borehole varied in direction. For the boreholes, a maximum drilling tolerance of 1% and a maximum admissible curvature radius of 500 m had to be observed. Deviations determined with a computer controlled borehole surveying procedure were found to be less than 0,5 %.

The initially 146 mm diameter core drillings were later widened to a final diameter of 273 mm. Well targeted rock massif masonry injections on a cement basis, enabled a significant stabilisation of the structure, particularly in he area of maximum anchor load application. Simultaneously the existing grout curtain was also improved. Water permeability tests provided evidence of me overall success of these measures.

5. STUMP Rock Anchors

The anchor design was based both on DIN 4125 and its licensing by the building inspectorate which however, applies to a max. working load of 2781 kN. Additional approvals were therefore required for the greater anchor loads needed, i.e. 4500 kN.

Each anchor's tie rod comprised 34 prestressing steel strands, type ST 1570/1770, having a nominal cross section (0.6") of 150 mm^2 each, and each strand being provided with a corrosion protection consisting of corrosion protection grease and polyethylene sheathing. In the area of the exposed steel length, the 34-strand bundle was additionally protected by a thick-walled (11 mm) polyethylene tube (picture 3).



pic. 3: cross section anchor with strands and fibre optic sensors.

In ten anchors an aramid rod is placed in the centre which contains an fiber optic sensor. For reasons of redundancy each sensor rod contains two separate sensor fibers over the complete anchor length.

Load was applied to the distribution beam via the corrosion protected anchor head. At the lower end of the anchor, the anchor load was transferred to the rock massif by bonding, the load application length being l_o = 10 m. In this area, the strands were without grease coating and polyethylene sheathing, with the corrosion protection provided by a common ribbed polyethylene tube and cement mortar. While still in the production plant, the ribbed polyethylene tube was cement mortar injected. Such cement mortar to DIN 4227 Part 5 also ensured sufficient bond with the adjacent rock. Safe transfer of the great anchor loads to both rock types had been successfully tested in advance using test anchors with loads of up to 12500 kN. The anchors were manufactured in the Stump site factory.

6. Anchor Installation and Prestressing

The anchors, transported from the site factory to the drilling point using feed rolls, were lowered into the borehole by means of a special guide system and a mobile crane (picture 4).

pic. 4.: installation of anchor

The space around the borehole and the anchor sheath were filled with cement mortar through integrated tubes and the anchor heads installed subsequently.

Tensioning of the anchors using ca 2 tonne-hydraulic presses was carried out from the load distribution beam's inside gallery, with the presses being operated by means of a special travelling and lifting device.

All operations were carried out on the basis of the quality assurance System established by Stump in cooperation with both Client and testing engineer. Strict compliance with the measures foreseen, a proper working procedure and reliable checks thus guarantee an optimal performance of the anchors, and particularly of the corrosion protection System.

7. Monitoring Concept

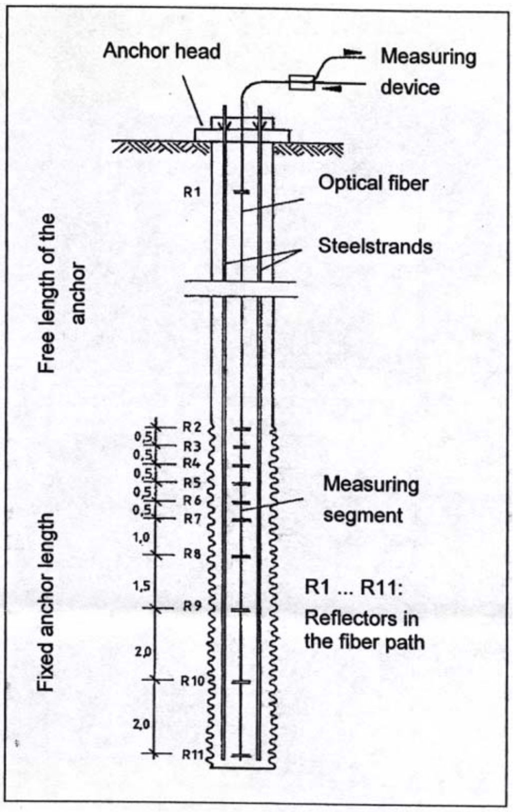
For permanent anchor monitoring, 10 out of the total number of 104 anchors installed were equipped with load cells and optical fiber sensors The heads of all anchors is so designed as to enable anchoring force measurements at any time using a light-weight cube tester (lifting test). Post-tensioning of the anchors is possible if and when required. The prestressing of all 104 anchors was finished in spring 1994.

8. Fiber Optic Sensor System

As described in chapter 5 ten anchors are equipped with an fiber optic sensor.

Along an optical glass fiber with a diameter in the range of 125 μm to 140 μm, markers were inserted at regular intervals. Two neighbouring markers represent a measuring section in the optical fiber. Its spacing can be determined by using an optical time domain sensing method. To create a long-gage-length sensor fibre for quasi-distributed (segmented) strain sensing, the optical fiber was physically segmented into discrete sections.

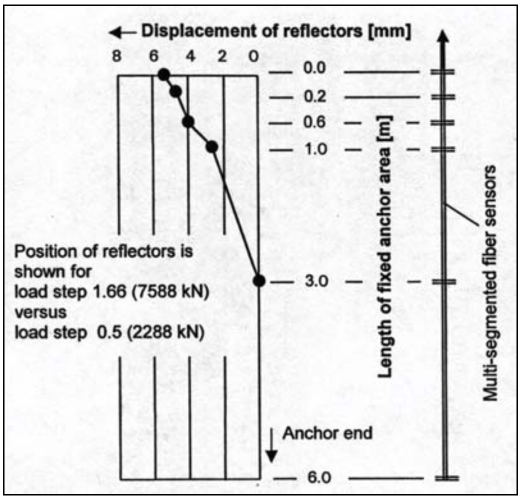
The markers are fiber splices (fixed connections between fiber ends) which partially reflect light transmitted through the fiber. These reflectors can be designed and positioned according to the measurement task. Figure 5 shows the position of the sensors R1 to R1 1. The first reflector R1 is fixed beneath the anchor head and does not change its position even if the anchor strain varies. The other reflectors R2 to R11 are positioned with relatively small spaces in the fixed anchor length area. The spacing in the upper part of the fixed anchor length, where the anchor forces will be transferred into the rock, was chosen to be more narrow and equidistant (0,5 m).



pic. 5: Simplified description of the sensor segments position inside the anchor

The spacing in its second part is 1.5 m or 2 m. The distance from R1 to 11 is 58 m and 63 m respectively. Here, we should acknowledge that the choice of several equidistant neighbouring reflectors increases the uncertainty of measurement because of a destructive interference of signals from several neighbouring reflectors.

Picture 6 shows the results of a suitability test in the stilling basin. The complete load transfer into the ground ends after 3 m fixed anchor length.

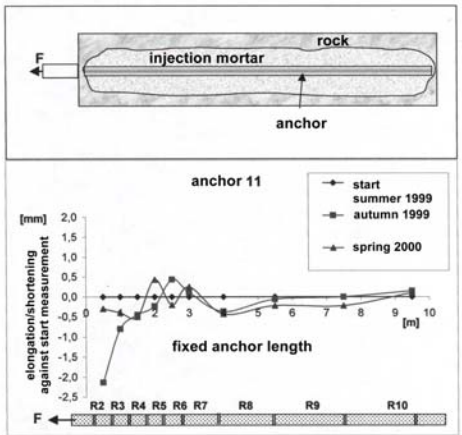


pic. 6: Result of suitability test

During the first years no measurements were taken by the fiber optic measurement device. Since 1998 the BAM (Federal Institute for Materials Research and Testing) carries out measurements with the installed sensors.

The continuos measurement starts in summer 1999 with a new reference campaign. The results are shown in picture 7. The measured values are confidential if they are < 0,9 mm. It is obvious that only at the beginning of the fixed anchor length an influence of the differing water level is recognisable.

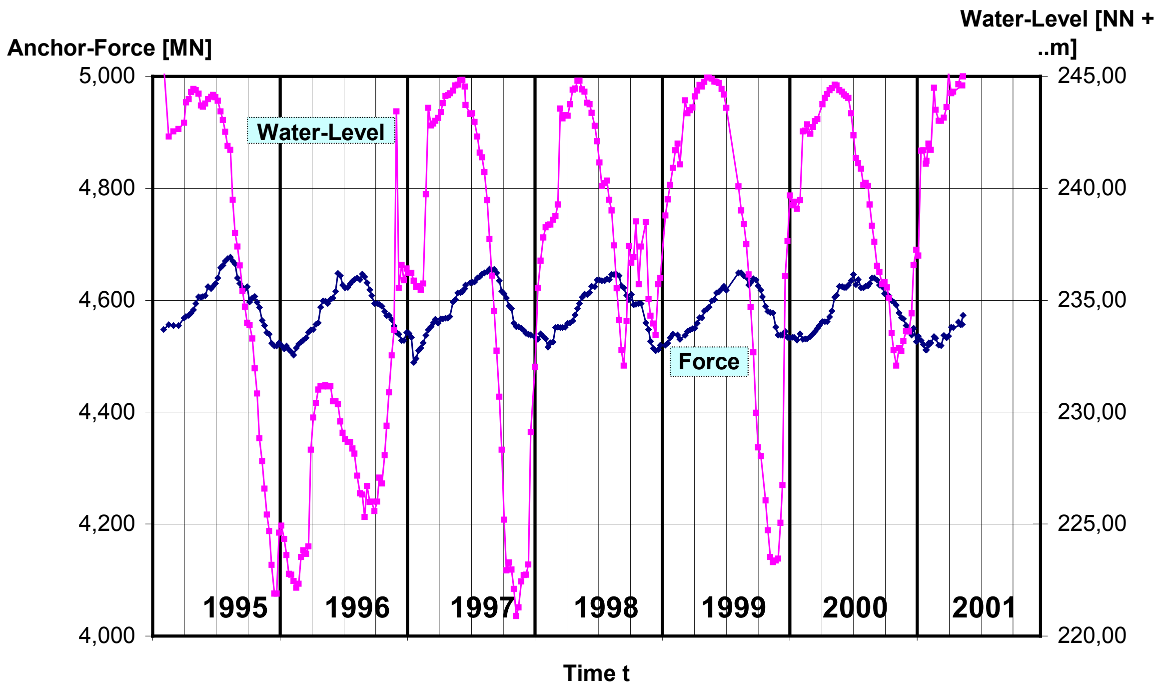
At the moment the BAM takes further research to improve the confidential line of the values up to 0,25 mm. But also with the actual device the monitoring of the integrity of the fixed anchor length is possible. Since the first prestressing the load transfer distance didn´t change, as it was expected.



pic. 7: measured displacements in the fixed anchor length by OTDR device

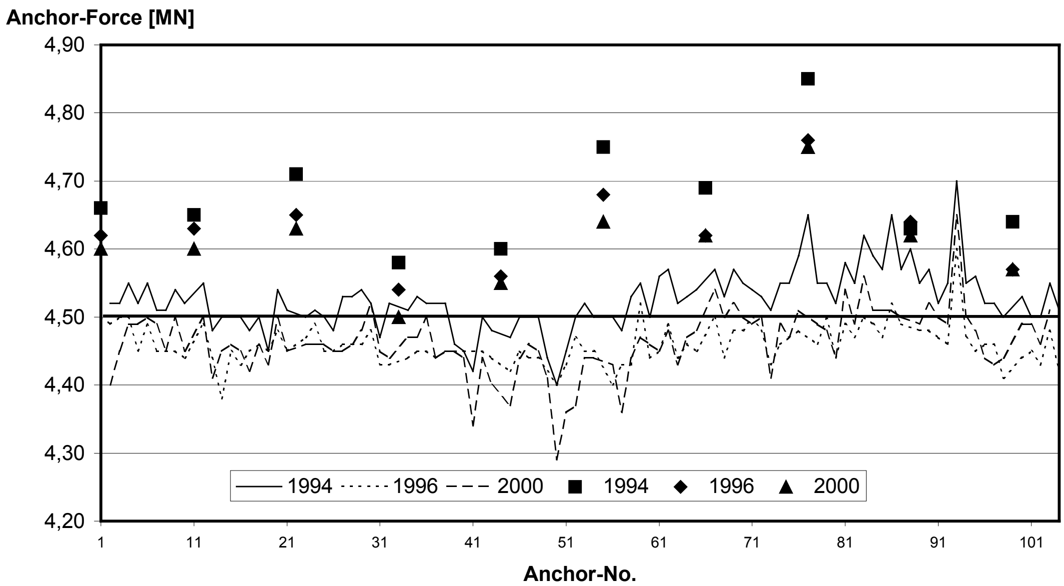
9. Inspection Gauges and Lift-off Tests.

As mentioned ten anchors are equipped with force-gauges system GLÖTZEL. The anchor loads are noticed every week, together with the temperature and the water level of the reservoir. The results are shown in picture 8. The relative great deviations in the anchor forces are influenced by the temperature. The water level in the reservoir has no significant influence on the anchor force. The main aspect of the 6 years measurement is, that there is no loss of anchor force is recognisable.



pic. 8: Anchor Force as function of time

At all anchors, except the gauge equipped ones, the force was controlled by lift-off tests for three times since 1994 (picture 9). The average force reduction is 1,35%. That is for a period of 6 years very low. Especially between 1996 and 2000 is nearly no further reduction. On the picture the results of the ten force gauges are also included. The measured anchor load is higher than the force from the lift of tests. The reason for this is that the lift off tests were carried out in the warm summer period, when the gauges show to high forces effected by the temperature.



pic. 9: Results from lift-off tests and anchor-gauges

10. Conclusions

The anchor monitoring programme at the Eder Dam demonstrates that permanent grout anchors are a save and long time solution for the improvement of dam stability, even with high anchor loads.
The control by force gauges and lift-off tests gives sufficient information about the anchor behaviour. Additional monitoring of the fixed anchor length by fibre optic sensors allows to control the load transfer into the surrounding rock. This measurement method will influence the design of fixed anchor length and research in load transfer in the future.

REFERENCES

[1] Feddersen, Ingo: Improvement of the overall stability of a gravity-dam with 4500 kN-anchors, Ground anchorages and anchored structures. Thomas Telford, London 1997

[2] Schwarz, Helmut: Neue Maßstäbe für die Bohr- und Ankertechnik, Edertalsperre 1994 Festschrift der Wasser- und Schiffahrtsdirektion Mitte, Hannover, 1994

[3] Habel, Wolfgang; Feddersen Ingo: Embedded quasi-distributed fiber-optic sensors for the long-term monitoring of the grouting area of rock anchors in a large gravity dam. Journal of intelligent material systems and structures Vol. 10, April 1999

[4] Dietz, Klaus; Schwarz Helmut: Heavy-duty anchors – report on unusual applications for grouted anchors. Ground anchorages and anchored structures, Thomas Telford, London 1997

Summary

In 1993/94104 permanent grout anchors, each with a working load of 4500 kN were installed at the Eder Dam, Germany to improve the over all stability. Such high anchor loads need a detailed long term performance monitoring system. For the first time fiber optic sensors were equipped in the fixed anchor length to measure the load transfer in the rock. The report informs about this measurement system and the results of the monitoring. The measured displacements are compared with the values of anchor gauges and lift-off tests.

Résumé

Le confortement du barrage de l'Edersee a été réalisé à l'aide de 104 tirants injectés permanentes en 1993/1994; chaque tirant ayant une charge de 450 tonnes. Ces tirants à très haute charge nécessitent un système de mesure et de surveillance très détaillé. Pour la première fois des capteurs à fibre optique ont été installés en vue de mesurer le transfert de charge du tirant à la roche. Cet exposé présente les méthodes de mesures et les résultats ainsi obtenus. Ces derniers sont comparés avec les mesures effectuées sur site par dynamomètre et essai de soulèvement.