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TEMPERATURE MEASUREMENT IN A MASONRY DAM BY MEANS OF FIBREOPTICAL SENSORES

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1. PROBLEM DEFINITION

Reservoirs fulfil several tasks by means of storing water over a long period of time. These tasks are flood control, supply of raw water for the population and industrial purposes as well as hydropower use. In general the public may see reservoirs and dams mainly from a recreational point of view, not least because the loads, which gravity dams or embankment dams must withstand over decades, are barely to detect for the public. Not perceptible measuring instruments survey the building and announce any irregularities immediately to the monitoring headquarters.

Gravity dams are stressed by two major loads. The first and most obvious type of load is water pressure according to the percentage of storage. By raising the reservoir level the hydrostatic pressure increases. Compared to an empty reservoir, the dam crest of a full reservoir is shifted downstream several centimetres.

The second type of load, which acts invisibly within the dam structure itself, causes deformations in almost the same quantity. Depending on the time of year, the temperature inside of the dam structure varies according to the water and air temperatures. This causes stress within the structure and deformation of the dam.

The knowledge of these temperature stresses is almost as important as the knowledge of the effect of the water load when regarding the safety of the dam. In order to prove the safety one uses calculatory stability analyses in which both loads mentioned above, beside further loads, are considered [3], [5].

Whereas the quantity of hydrostatic pressure can easily be derived from the height of storage, not much is known about temperature loads.

This is why the guideline 222 [4] of the German Association for Water Resources and Land Improvement (DVWK) suggests the installation of temperature sensors in three measuring lines with five measuring points each. With this mean the temperature distribution within the dam structure can be observed throughout the first 3 to 5 years after inauguration.

Current equipment act as electronic temperature measuring instruments using temperature-dependent resistance which are placed in boreholes in the dam structure. These instruments allow temperature measurements in certain points. In-between the points the temperature distribution has to be estimated [2].

Current research results show that surveillance of dams and stability evaluations are only possible by using the exact temperature distribution within the dam structure [1].

2. DISTRIBUTED FIBRE OPTIC TEMPERATURE SENSING

Opposite to conventional measuring techniques, fibre optic temperature measuring techniques [6] using glass fibre cables enable localised measurements within a structure and at its surface along a line form. Normal glass fibre cables, as used in the field of telecommunications or data processing, serve as measuring instrument. These cables may additionally be equipped with protective sleeves or strain relief items.

The measuring procedure is based on OTDR (optical time domain reflectometry), known from the optical communications technology.

A laser source launches pulses of light into the sensing fibre using an optical fibre wavelength division multiplexer (s. figure 1). The light pulse is continuously attenuated along its way through the glass fibre cables. This attenuation in the glass fibre cable is caused by absorption on the one hand but merely by dispersion.

A small portion of the strewn light is scattered backwards, so that it runs as a continuous reference dimension (so-called backscattering light). There it will be received by a transmitter.

The intensity of the backscattered light is far smaller than the magnitude of the original impulse. The signal won by the photodiode in the recipient is therefore extremely noisy. For that reason, merely a signal processing with digital averaging supplies useful reference dimensions.

The analysis of the backscattered signal basically takes place, as soon as the laser does not supply light, thus in the break between the light pulses. Therefore one tends to operate with as short impulses and long tracing as possible. A backscattered signal is analysed as long as the linked light pulse passes through the glass fibre cable up to the end and the signal backscattered from there reaches the recipient again. Subsequently, a new light pulse is produced by the laser and a further backscattering curve develops.

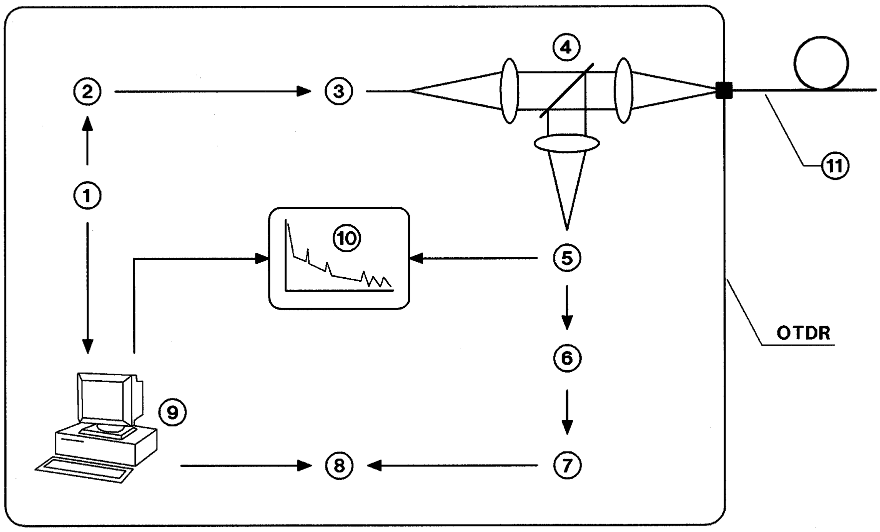

Figure 1: Backscattering procedure

Le procédé de backscattering

1	pulse	impulsion
2	laser operator	opérateur de laser
3	laser	laser
4	coupler	coupler
5	optical receiver	récepteur optique
6	A/D – changer	A/D – comutateur
7	digital calculator	calculatrice digitale
8	memory	mémoire
9	computer	ordinateur
10	oscillograph	oscillographe
11	fibre optic cable	câble à fibres optiques

The clock frequency of the laser thereby limitates the max. possible run time of the impulse and thus the max. length of the glass fibre cable:

$$\text{length } l = \frac{ct}{2n}$$

with: t: Run time of the light pulse

½ in order to consider both ways

c: speed of light in the vacuum

n: refractive index of the fibre-optic cable

With this connection any other distance (e.g. to a certain point in the glass fibre cable, where the backscattered signal changes significantly) is determinable, if the appropriate run time is known.

The signal arriving in the recipient is scanned with a high frequency f_A (period duration t_A). The dissolution of the system is higher, the shorter the period duration lasts.

Dissolution: $$R_1 = \frac{ct_A}{2n} = \frac{c}{2nf_A}$$

with R1: dissolution

t_A: sensing interval

f_A: sampling rate

One has to take into account that the dissolution can never be better than the appropriate width of the laser impulse. This is the main reason, why one uses as short an impulses as possible. On the other hand a reduced impulse leads to a small energy within the impulse and reduces the backscattered signal which already is very small itself. Depending on the measuring task, a suitable compromise between spatial dissolution and signal quality has to be chosen.

The process and the amplitude of the backscattered signal include the reference dimensions. With a completely homogeneous glass fibre cable with steady outside conditions on its entire length, the linked light pulse will be exponentially absorbed according to a fundamental physical law with increasing time respectively appropriate distance. The same occurs with the backscattered light running backwards. The backscattered curve therefore always tends to have an exponentially falling process, which however is traced as a falling straight line due to the logarithmic scale within the measuring instrument.

Any inhomogenities or altered outside conditions along the glass fibre cable, causing an additional absorption, are visible as discontinuities in the backscattered picture.

How outside conditions influence the dispersion particularly depends on the type of the dispersion. Three types of dispersion are of importance in glass fibre cables (s. figure 2):

- Rayleigh scattering (relatively high intensity, no wavelength shift)
- Brillouin scattering (small intensity, small symmetrical wavelength shifts lead to so-called Stokes and anti-Stokes)
- Raman scattering (small intensity but larger wavelength shifts than Brillouin scattering)

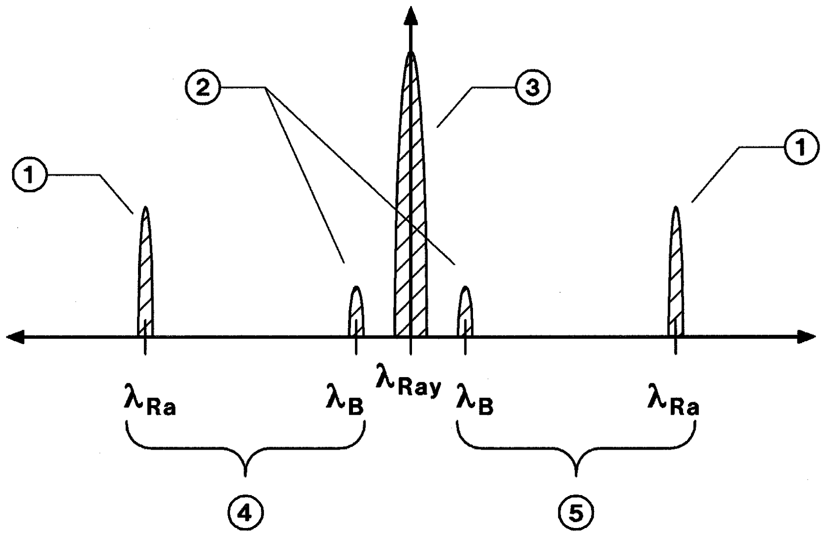

Figure 2: Dispersion in glass fibre cables

La dispersion dans les câbles à fibres optiques

1	Raman scattering	Raman dispersion
2	Brillouin scattering	Brillouin dispersion
3	Rayleigh scattering	Rayleigh dispersion
4	Stokes	Stokes
5	Anti Stokes	Anti Stokes

Whereas Rayleigh scattering is used throughout the optical communications technology in order to analyse laid glass fibre cables with OTDR devices, the distributed sensor technology takes advantage of Brillouin and Raman scattering.

The Brillouin scattering is used with the distributed Strain measurement (Optical fibre strain measurement system AQ-8601, Ando company). The predominant number of publications however deal with the distributed fibre-optic temperature measurement on the basis of the Raman scattering [8], [10]. At present it is the only commercially available technique [7], [11].

The appropriate Stokes are filtrated with narrow optical filters from the spectrum of the entire backscattered signal. The Raman Stokes are displaced around $\pm 440\ cm^{-1}$ in relation to the original wavelength; in glass fibre cables that amounts to a wavelength shift of approx. ±100 nm at a spectral width of about 50 Mhz.

A crucial factor for the temperature measuring procedure is that the intensity of the Stokes needs to be strongly temperature-dependent, whereas the intensity of the anti-Stokes has to be temperature-independent. Forming a relation of both intensities, one receives a quantity for the temperature, simultaneously suppressing disturbing influences (e.g. absorption spots in the glass fibre cable):

$$\frac{I_A}{I_S} = \left(\frac{\nu_O + \nu_k}{\nu_O + \nu_k} \right)^{\$} e^{-\frac{hc\nu_K}{kT}}$$

with: I_A: intensity of the anti-Stokes

I_s: intensity of the Stokes

ν_o: Wavenumber of the linked light amount

ν_K: shift of the Wavenumber

T: absolute temperature in °K

k: Bolzmann- constant

h: Planck‘ quantum of action

c: speed of light in the vacuum

The equation above proves that the result -apart from the Wavenumber shift- is only dependent on the absolute temperature. Thus the fibre-optic distributed temperature sensing is a highly exact procedure with an above average distance neutrality. The sensitivity of the procedure amounts to approx. 0,8 %/°C when using glass fibre cables.

When dealing with, the Wavenumber shift, which exclusively depends on the type of material of the glass fibre cable, proves tolerance afflicted. So-called gradient glass fibre cables are used as sensors. It is named after the gradual transition of the refractive index of the glass fibre cable from the core centre to the side edge. In order to obtain this refractive index, the base material to be doped during the production of the glass fibre cable (SiO_2) and this doping be continuously modified. This way the material properties become technology dependent and the Wavenumber shift tolerance afflicted merely in a small degree. The measuring errors resulting from this are balanced by calibrating the measurement. For this purpose a section of the glass fibre cable is heated with a defined temperature during the measurement, e.g. with the help of warmed water.

Typical parameters of fibre-optic distributed temperature sensoring today are:

absolute accuracy: ±0,3°C with -50°C... 80°C

sensor length: 20 km

working conditions: -140°C... 450°C at pH values >2 and

pressures up to 75 Mpa

The accuracy and the reproductibility attainable during operation depends mainly on to which degree one succeeds to improve the signal-noise-ratio by averaging. This can be illustrated by the following case: during a typical laser impulse output of 100 mW a measurement (averaging contained) lasts e.g. 60 s. A repetition of 256 times for example reduces the measurement error by factor $\sqrt{256} = 16$.

3. CONVERSION AT THE ENNEPE DAM

In order to examine the practicability of this technology an appropriate glass fibre cable was built into the almost 100 years old Ennepe dam of the Ruhr River Association apart from conventional measuring techniques. The Ennepe dam, a 320 m long and 51 m high gravity dam, is a masonry structure and was built between 1902 and 1904 in order to regulate the discharge of the Ennepe river to provide a reliable supply for the generation of hydropower on the lower reaches of the river even in periods of draught.

Initially the dam was 41,4 m high, giving a storage capacity of 10,3 x 10^6 m^3. Between 1910 and 1912 a masonry block with a height of 10 m was added to the crest of the dam. Since then the reservoir has 12,6 x 10^6 m^3 at the disposal. The Ennepe dam was at the time, designed in accordance with the basic design principles Professor Intze established for the early masonry dams, taking no account of pore pressure or uplift. As usual at many old masonry dams, a drainage system consisting of vertical stoneware pipes had been installed immediately behind the upstream face of the dam. These drainage pipes had been unintentionally filled with grouting material during repair works in 1959. This problem was detected by the German Reservoir Supervision Authority at the beginning of the 1980s. The Authority specified the Ennepe dam be modified immediately in order to meet the established national technical standards which were based on the current view of the physical effects of uplift. Due to the fact that the former owner was financially not capable to undertake these modifications, the Ruhr River Association took over the dam in 1997 and immediately began to upgrade it [9].

The concept for modification and rehabilitation was mainly based on the construction of a drainage and inspection gallery, from which new drainage holes could be bored to drain the masonry structure and bedrock (s. figure 3).

In addition to this and in order to evaluate the temperature stresses within the masonry structure, the dam was equipped with two measuring sections with four boreholes each. These were fitted out with 32 temperature gauges of the type PT100 (s. figure 4). Another two temperature gauges in the reservoir and on the downstream face, as well as three gauges in the crest round off the measuring program.

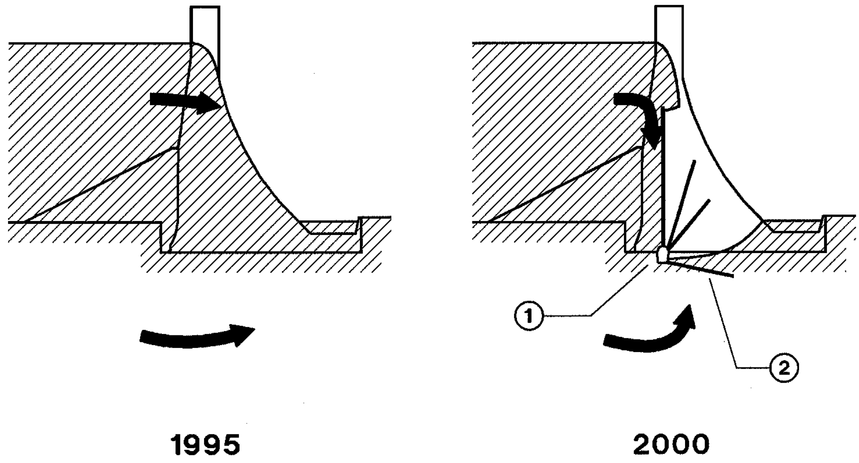

Figure 3: Concept for modification of the Ennepe dam

Concept pour la modification du barrage d'Ennepe

1	drainage gallery	galerie de drainage
2	drainage boreholes	forage de drainage

The gauges are connected to three Datataker, which themselves are controlled by a PC. The measuring frequency can be adjusted in various ways. A measurement every ½ hour proved to supply sufficient data.

This configuration of altogether 35 gauges within the masonry structure clearly exceeds the recommended number in the DVWK guideline of 15 gauges. However the temperature can only be measured at these 35 points and not within the areas between these points.

For comparison purpose and for testing of the measurement techniques a continuous glass fibre cable was pulled through all boreholes. The cable was resumed up to the crest of the dam through a connecting borehole, where it was placed into the reservoir as well as onto the downstream face of the dam.

The entire cable length amounts to approximately 800 m, of which 217 m is used as effective measuring section. The remaining length serves as feeding. Two sorts of glass fibre cables were used.

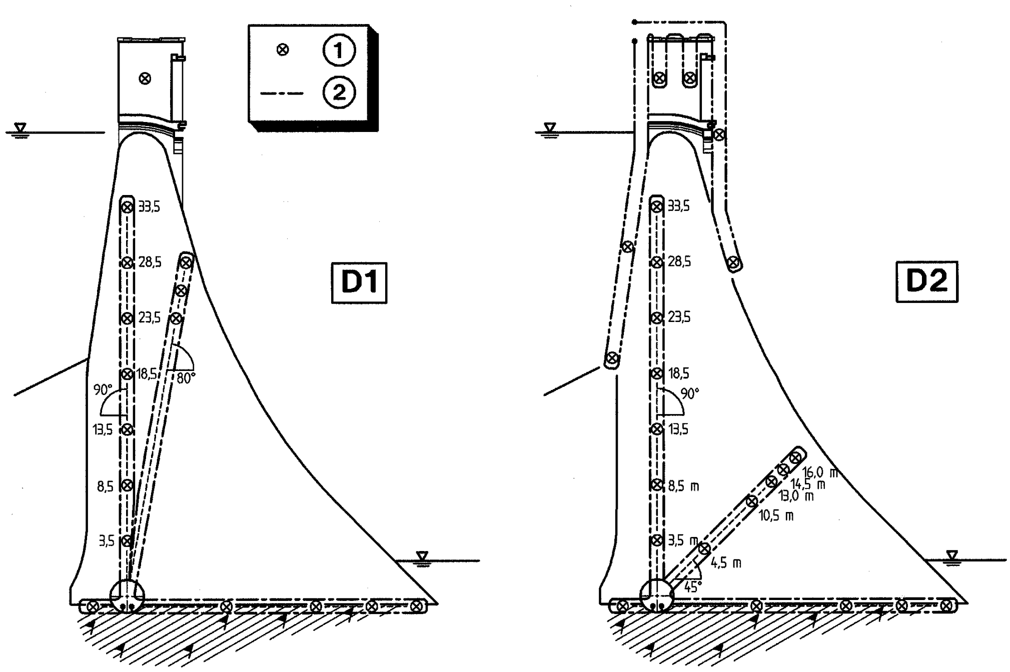

Figure 4: Temperature measurement installations in profiles D1 and D2

Installations de mesure de la température dans les sections D1 et D2

1 temperature sensor PT 100 capteur de température PT 100
2 fibre optic cable câble à fibres optiques

A cable of the type A-D(ZN)2Y 4 G 50/125 1 F 600 N (designation according to DIN VDE 0888) was used in the dam structure. It consists of a central bundle wire with four optical fibres and a gel filling. A expanding tape serves as longitudinal water protection. Additionally it possesses a non-metallic strain relief and an intensified protective sleeve. The areas outside of the dam structure were equipped with a cable of the type A-D(ZN) 2Y B2Y 4 G 50/125 3 B 400 F 600, which is surrounded by a PE outer casing.

4. CONCLUSIONS

4.1. INSTALLATION

The installation of the optical waveguide cable took place together with the PT100-temperature gauges. The glass fibre cable was inserted as a loop into the borehole and the upper end received a defined radius with the help of a guide pulley, in order to prevent the cable from breaking (s. figure 5). The guide pulley and cable were inserted into the borehole using an installation linkage. This linkage additionally served as girder for up to seven temperature gauges, which were accommodated in the same borehole. The remaining cavity of the borehole was then filled, in order to exclude a hydraulic connection and possible heat transport between the gauges.

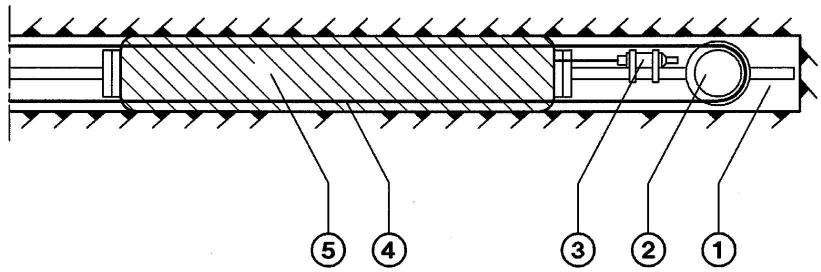

Figure 5: Installation situation of the temperature gauges and glass fibre cables inside the borehole

Situation d'installation des jauges de température et des câbles à fibres optiques

1	installation linkage	liaisob d'installation
2	obligated bend	courbure obliqée
3	temperature sensor PT 100	capteur de température PT 100
4	fibre optic cable	câble à fibres optiques
5	packer	obturateur

Due to the good scheduling of the work done by the company, in particular a pre-assembly of the gauges on the installation linkage and the marking of linkage sections, all gauges were inserted into the boreholes in one day. The laying of the glass fibre cable, which was meant to avoid absorbing joints and which had to be inserted in one piece, proved difficult. At this point the installation plan, which had been set up beforehand, helped the several hundred meters long cable not to be knotted.

The filling and injection of the boreholes could already be done the following day. In order to protect warranty claims the manufacturer of the measuring instruments was responsible also for these works.

4.2. OPERATION OF THE MEASURING SYSTEM

After the simultaneous installation of both measuring systems into the dam, the temperature measurements with the help of the glass fibre cable began at the end of December 1998. For different reasons the conventional measuring system was only ready for use at the beginning of May 1999.

Since then the glass fibre temperature measurements are carried out on a monthly basis. This process is according to the demands of the DVWK guideline. The measurements are carried out by the manufacturer of the measuring system, who also provides the laser unit for every measurement. Automatic laser measuring instruments are not yet available. Therefore each measurement requires the manufacturer and his measuring instrument, as well as specially trained technical personnel. The results are prepared in tabular and graphic form.

Since the installation was carried out, none of the two measuring systems has yet been affected. Only once the glass fibre cable was split, when dealing with drilling equipment inside the inspection gallery. The point of failure was repaired without any problems. However it represents a defective area in the glass fibre cable causing small absorption.

The life span of the components is important for long-term operation. The electronic PT100-temperature gauges are components, which have proved their quality and availability in many applications. Nevertheless damages to the components e.g. caused by overvoltage due to lightning strokes can occur. In contrast to this, the simple design makes glass fibre cables durable and their longevity has been proved throughout the communications technology.

5. MEASURING RESULTS

5.1. RESULTS OF THE GLASS FIBRE TEMPERATURE MEASUREMENTS

The results of the glass fibre temperature measurements will be described exemplary for the boreholes D22 and D23 for the cross-section D2 (s. figure 4).

Borehole D22 is 33,5 m long and reaches upwards perpendicularly from the drainage and inspection gallery. It is equipped with 7 electronic sensors; the distance between them counting 5 m. The length of borehole D23 is 16 m and it is equipped with 5 electronic sensors. The glass fibre cable was additionally inserted in both boreholes.

The results of the glass fibre temperature measurements are illustrated in figures 6 to 9. The fine dissolution of the measurement cable shows the heat flow from the outside into the concrete dam (s. figure 7). The uppermost point of the diagonal borehole D23 is approx. 2 m away from the outer surface of the dam. The temperature within this wall area amounts to about 8 °C at the beginning of the measurements in December 1998 and continues to drop until February. Subsequently the temperature rises up to almost 13 °C in July 1999. The internal dam structure warms up far slower. About 5 m away from the uppermost point of borehole and thus 7 m away from the outer dam surface, the temperature only changes slightly. At the foot of the borehole, close to the inspection gallery, the first 2 m are influenced by the temperature in the gallery itself.

The vertical borehole D22 (s. figure 6) shows similar temperatures. Its uppermost point is close to the upstream dam surface. In the summer of 1999 the water level in the reservoir dropped several meters, so that the upper section of the dam was warmed up from both sides by air. Additionally the upstream surface of the dam pointing southwards was warmed up by solar radiation. The temperatures in the borehole therefore rose up to 20 °C. One can clearly see the bend in the temperature curve at a depth of approx. 18 m. As for the masonry structure beneath, the temperature changes are barely concerned.

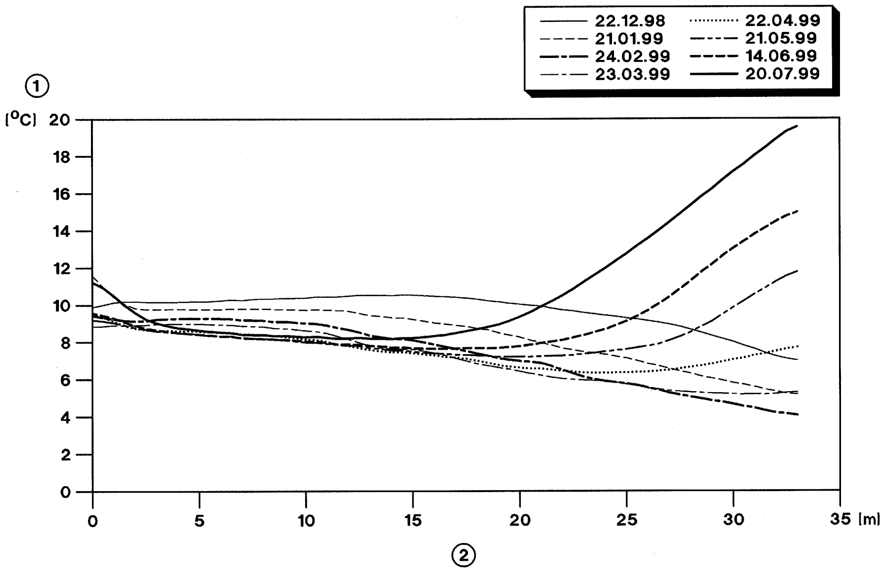

Figure 6: Temperatures along borehole axle D22 at different times

Les températures le long de l'axe de forage D22 au différent de périodes

1	temperature	température
2	depth of borehole	profondeur de forage

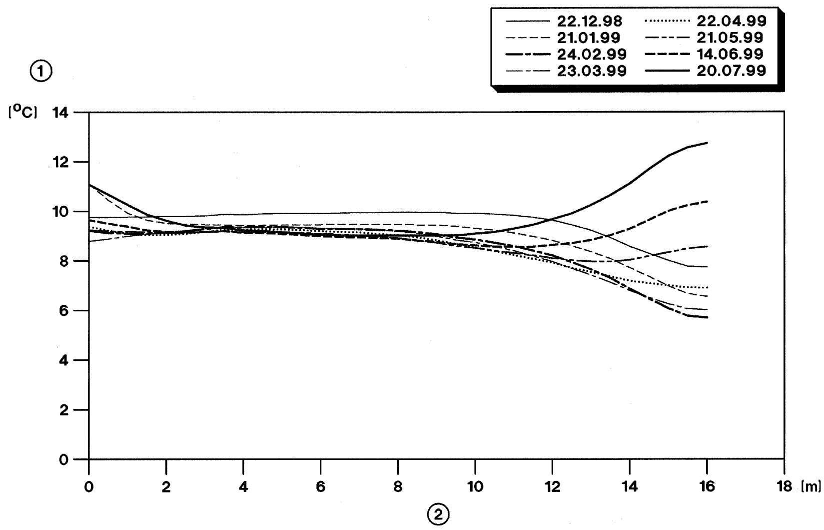

Figure 7: Temperatures along borehole axle D23 at different times

Les températures le long de l'axe de forage D23 au différent de périodes

1	temperature	température
2	depth of borehole	profondeur de forage

Figures 8 and 9 illustrate the temperatures in the boreholes to a time axis. The fat continuous line traces the temperature course at the uppermost point of the borehole, whereas the fat stroke-dot line graphs the temperature course at the foot of the borehole, close to the inspection gallery. The fat dotted line shows the temperature inside of the dam structure, about 2,5 m away from the inspection gallery. The measuring curves of further sections of the glass fibre cable are arranged between these lines. The diagram clearly shows the temperature gradient from the inspection gallery (about 10 °C) towards the outside of the dam structure (about 7 °C). By February the dam is cooled down and the temperature distribution changes in April/May. The external dam areas warm up, while the internal areas remain at a temperature of approx. 10 °C.

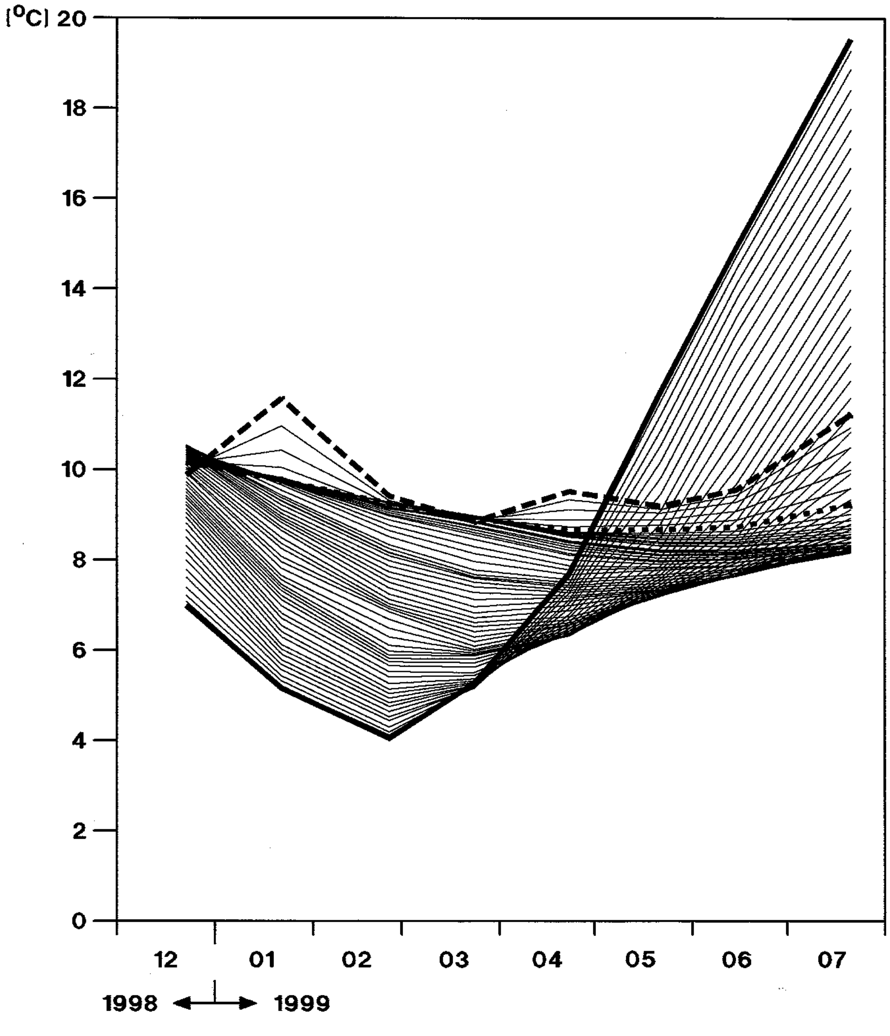

Figure 8: Temperatures in borehole D22 to a time axis

Les températures dans le forage D22 à l'axe de temps

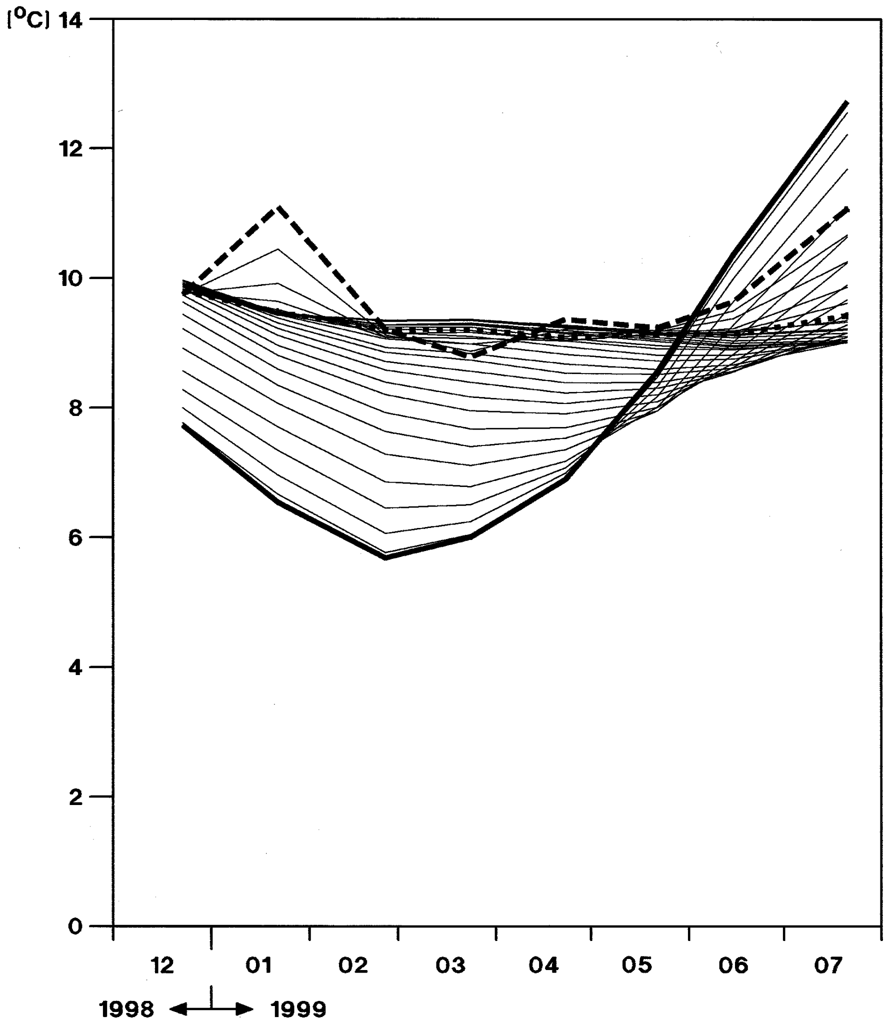

Figure 9: Temperatures in borehole D23 to a time axis

Les températures dans le forage D23 à l'axe de temps

With the help of the measured temperatures along the boreholes, one can easily prepare the temperature distribution in the dam structure at a certain time. A simple linear interpolation is given in figure 10. Higher-grade procedures e.g. according to the Finite-Element Method (FEM), supply temporally and spatially detailed data of the temperature distribution on the basis of measuring results. The author already reported on this topic in [1].

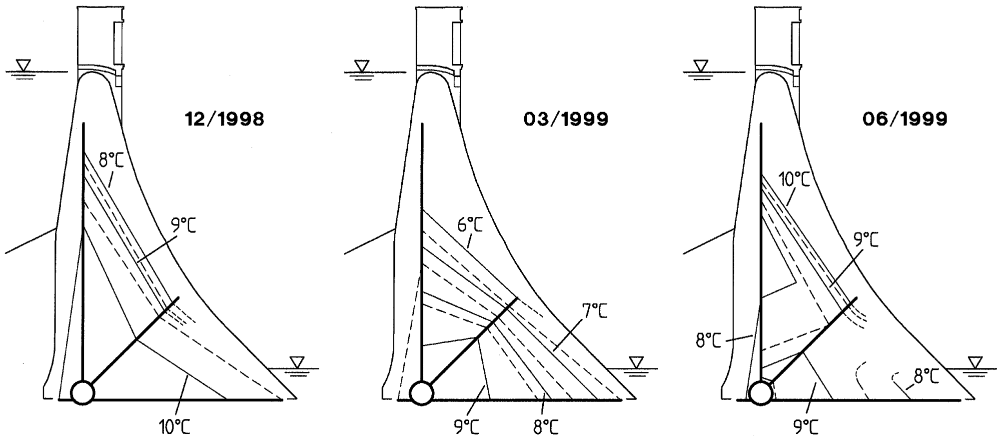

Figure 10: Temperature distribution in the dam structure in December, March and June

Distribution de la température dans la structure du barrage en Décembre, Mars et Juin

5.2. COMPARISON OF THE MEASURING TECHNIQUES

The technical possibilities need to be compared, in order to compare the results of the glass fibre temperature measuring technique with the conventional measuring technique. The technically simple designed glass fibre cable can be used for temperature measurements with a complex laser measuring instrumentation. At the Ennepe dam the measuring accuracy was set to 0,3°C and the local dissolution was adjusted to 0,50 m. The number of data points within the measuring section of the glass fibre cable (length = 217 m) therefore corresponds to 434 conventional measuring instruments.

The employed PT100-temperature gauges of the conventional temperature measurement system achieve an accuracy of 0,02°C. They must however be cabled individually. For measuring either a portable measuring unit (which has to be manually attached to every single instrument) is necessary, or a complex data processing, which permits a continuous measurement with the help of datataker an personal computers. The last was implemented at the Ennepe dam. The measuring interval was set to ½ hour.

The direct comparison of the measurement results at measuring points according to the conventional measuring system is shown in figure 11. The measurement results of the two measuring systems plotted against each other are almost on a straight line. The matching trendline has a certainty degree of 99%. The results are thus comparable. However a constant offset among the measurements of for about 1°C must be assumed as calibration error of the glass fibre measurement.

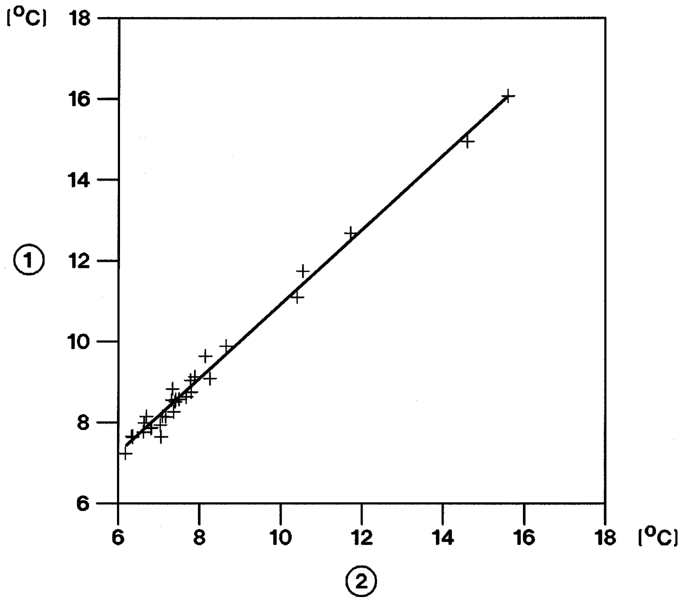

Figure 11: Comparison of the temperature measurement results on 14.06.99

Comparaison des résultats de mesure de la température pour 14.06.99

1	fibre optic cable	câble à fibres optiques
2	temperature sensor PT 100	capteur de température PT 100

Figure 12 shows the measured temperatures (both procedures) in borehole D22 on 14.06.1999 along the borehole axle.

The 67 measuring points of the glass fibre cable almost continuously reproduce the temperature course.

A comparable course on the basis the seven PT100-temperature gauges can only be determined with the help of an interpolation. Had only three gauges (instead of the seven) been inserted according to the recommendations of the DVWK guideline, the determination of the temperature course would have been additionally made more difficult.

The side effects at the foot of the borehole can be observed only with the glass fibre cable.

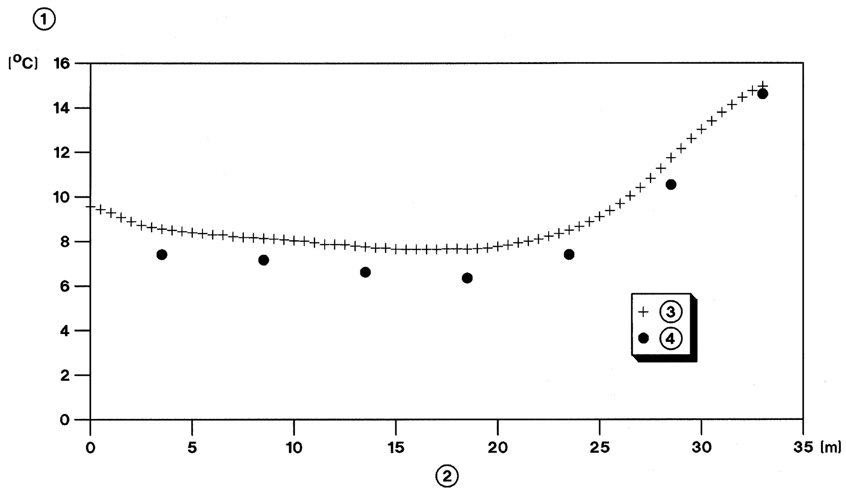

Figure 12: Temperatures in borehole D22 on 14.06.99

Les températures dans le forage D22 en 14.06.99

1	temperature	température
2	depth of borehole	profondeur de forage

6. CONCLUSIONS

An evaluation of the results of the glass fibre temperature measurement in the comparison to the conventional measuring technique is only possible regarding the requirements of dam monitoring respectively up-to-date standards. In this concern the already mentioned DVWK guideline writes:

"Because the shifting (of gravity dams) are strongly influenced by the temperatures inside dam structure, usually temperatures need to be measured... During dam construction temperature measurements indirectly inform on expectable stresses inside the dam structure. ... For this reason installed measuring instruments can normally be used for temperature measurements during long term dam operation.

The guideline furthermore claims the installation of temperature gauges in at least 3 measurement lines with 5 measuring points each inside the dam, in order to registrate the temperature distribution in the dam structure within the first 3 to 5 years after construction by means of monthly measurements.

Both, the glass fibre measuring technique as well as the conventional measuring technique, fulfil these requirements. Also regarding the requirements during installation, both techniques are to be regarded as equivalent.

The differences result, as soon as a locally fine-resolving measurement is required or if many measurements have to be carried out during a long period of time.

The installation of a minimum measuring system with 15 measuring points of the conventional measuring technique type certainly is the cheapest solution (see table), particularly if the measurements are carried by hand.

	conventional measuring technique	**glass fibre measuring technique**
Amount of measuring points	40	measuring section 217m, with 434 measurement points
Accuracy	0,02°	0,3°
Cost of a temperature gauge (PT100)	140 EUR	-
Total costs of the temperature gauges/ glass fibre cable	5.600 EUR	4.000 EUR
Total costs of the temperature measuring system (gauges + additional equipment, without installation)	7.500 EUR	5.800 EUR
Cost of a single measurement	550 EUR	1.100 EUR
Stationary measurement system incl. PC	15.500 EUR	approx. 25.000 EUR

Table: Parameters and costs of the temperature measuring system at the Ennepe dam

Paramètres et prixs de la technique de mesurage de température du barrage d'Ennepe

If spatially fine-resolving temperature distributions are to be determined and if a measuring accuracy of 0,3° is sufficient, then the glass fibre technique offers a low-price possibility to measure temperatures.

However the lacking possibility of an automated measurement currently still proves disadvantageous, because the required laser measuring instruments are still in the stage of development. The cost-intensive measurements must therefore be carried out by specialised companies.

Complete solutions with Datataker and PC control are available for the conventional measurement technique with PT100 temperature gauges and can be recommended for long-term automatic measurements.

After completion of the experimental phase, the temperature measurements at the Ennepe dam will -for this reason- first of all be continued with the conventional measuring technique. The installed glass fibre cable will however be available without additional expenditure and may be used again for measurements at any time.

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SUMMARY

Gravity dams are stressed by two major loads. The first and most obvious type of load is water pressure according to the percentage of storage. The second type of load, which acts invisibly within the dam structure itself, causes deformations in almost the same quantity. Depending on the time of year, the temperature inside of the dam structure varies according to the water and air temperatures. This causes stress within the structure and deformation of the dam.

Current equipment act as electronic temperature measuring instruments using temperature-dependent resistance which are placed in boreholes in the dam structure. These instruments allow temperature measurements in certain points. Opposite to conventional measuring techniques, fibre optic temperature measuring techniques using glass fibre cables enable localised measurements within a structure and at its surface along a line form. The measuring procedure is based on OTDR (optical time domain reflectometry), known from the optical communications technology.

A laser source launches pulses of light into the sensing fibre. A small portion of the strewn light is scattered backwards along its way through the glass fibre cable, so that it runs as a continuous reference dimension (so-called backscattering light). There it will be received by a transmitter. Any inhomogenities or altered outside conditions (as for example the temperature) along the glass fibre cable are visible as discontinuities in the backscattered picture.

In order to examine the practicability of this technology an appropriate glass fibre cable was built into the almost 100 years old Ennepe dam of the Ruhr River Association apart from conventional measuring techniques. The entire cable length amounts to approximately 800 m, of which 217 m is used as effective measuring section. In addition to this the dam was equipped with 32 temperature gauges of the type PT100.

Both, the glass fibre measuring technique as well as the conventional measuring technique, fulfil the requirements of supervising the dam. The differences result, as soon as a locally fine-resolving measurement is required or if many measurements have to be carried out during a long period of time. The installation of a minimum measuring system with 15 measuring points of the conventional measuring technique type certainly is the cheapest solution, particularly if the measurements are carried out by hand. If spatially fine-resolving temperature distributions are to be determined and if a measuring accuracy of 0,3° is sufficient, then the glass fibre technique offers a low-price possibility to measure temperatures.

SOMMAIRE

Des barrages-poids sont soumis aux deux chargements principaux. La pression de l'eau selon le degré de remplissage est le premier chargement et le plus important. Le deuxième type de chargement, qui agit invisiblement dans la structure du barrage elle-même, cause des déformations aussi fortes que le premier chargement. Selon la période de l'année, la température à l'intérieur de la structure du barrage change en accordance des températures de l'air et de l'eau. Les contraintes resultant dans la structure causes donc des déformations du barrage.

Les équipements actuels sont des instruments électroniques de mesurage de la température utilisant la résistance température-dépendante et sont placés dans les forages dans la structure du barrage. Ces instruments permettent de mesurer de la température dans des points bien déterminés. Vis-à-vis des techniques de mesurage conventionnelles, les techniques de mesurage de la température utilisant des câbles à fibres optiques permettent des mesurages localisées sur une ligne dans l'intérieur d'une structure et à sa surface. Le procédé de mesurage est basé sur OTDR (optical time domain reflectometry), connu de la technologie des transmissions optiques.

Une source de laser lance des impulsions de lumière dans le câble à fibres optiques. Une petite partie de la lumière répandue est dispersée vers l'arrière le long de sa voie par le câble à fibres optiques, de sorte qu'il fonctionne comme dimension continue de référence (prétendue “backscattering light”). Là, elle sera reçue par un émetteur. Tous les inhomogenités ou conditions extérieures modifiées (comme par exemple la température) le long du câble sont visibles comme les discontinuités dans la “backscattered picture”.

Afin d'examiner la praticabilité de cette technologie, un câble à fibres optiques approprié a été installé dans le barrage d'Ennepe (environ 100 ans) du Ruhrverband (l'association de fleuve Ruhr) indépendamment des techniques de mesurage conventionnelles. La longueur du câble entière s'élève à à peu près 800 m, dont 217 m sont utilisés de section de mesurage réele. En plus, le barrage a été équipé avec 32 jauges de température du type PT100.

La technique de mesurage au câble à fibres optiques remplissent les conditions de surveillance du barrage aussi bien, que la technique de mesurage conventionnelle. Les différences sont visibles, dès qu'une mesurage fine sera exigée localement ou si beaucoup de mesurages doivent être effectuées pendant une longue période. L'installation d'un système de mesurage minimum avec 15 points de mesurage du type de technique conventionnels est certainement la solution moins chère, en particulier si les mesurages sont effectuées à la main. Si des distributions fines de la température dans l'espace doivent être déterminées et si une exactitude de mesurage de 0,3° est suffisante, alors la technique des câbles à fibres optiques offre une possibilité du prix bas pour mesurer des températures.

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