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The use of electronic-based systems in dam surveillance

The capture and processing of readings

Working group for the monitoring of dams – 1993

Part 1: General concept

Part 2: Possible applications

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The capture and processing of readings
Part 1: General concept

Working group for the monitoring of dams – 1991
Revision of document "Automation in dam surveillance" 1982

1. Definition

By the terms "the use of electronic-based systems in dam surveillance: the capture and processing of readings" we mean the use of electronic and computer based methods which enable readings to be carried out (continuously, at regular intervals, or on demand) of the values of the parameters characterising the behaviour of a dam with the possibility of printing them out or storing them, with a view to immediate interpretations by comparisons with limit values or by comparisons with other reference values. The definition includes all equipment used in the capture and continual recording of one or several physical measures at the point of capture, through to the equipment used for the computer processing and immediate interpretation on-site, at a centralised operating room or in an engineering office.

2. Basic principles

Automation needs not always be used in dam surveillance. Frequent visits to the structure and manual readings enable the behaviour of a dam to be satisfactorily monitored and allow any anomalies in behaviour patterns to be detected at an early stage.

However, the automatic taking and processing of the typical readings has the particular advantage of following developments across time without delays or interruptions. Moreover, the surveillance becomes essentially continuous when the readings are transmitted over long distances and processed in an office of the dam's operator.

Electronic dam surveillance systems complement the classical monitoring system without replacing it.

As a rule, the capture and automatic processing of readings only offer a selective picture of the behaviour of the dam and its surrounding area. Both the taking and transmitting of readings are not free from errors. It is not possible therefore, to totally abandon visual inspections and manual measurements.

The inspection of a dam does not only involve the taking of readings; visual checks play an important role, often forming an indispensable basis for later interpretations of the readings. They have to be taken on a weekly to monthly basis depending on the importance of the structure, the effective loading on the structure and the type of readings automatically taken and transmitted.

In addition, periodic checks on the measurement chain must be carried out manually (typically once a month). Exceptions can be allowed, for example, in the case of dams where access is difficult in winter.

The use of computers can both simplify the monitoring and speed up the inspections if the manual readings are transmitted to the person in charge by telephone, modem or fax the same day as the reading. By these means of communication, inspections can be carried out rapidly and, should the occasion arise, dubious readings can be repeated immediately under practically identical conditions.

The use of an automated system in the capture and processing of some of the dam readings does not mean that the work performed by personnel in charge of the inspection will be put into question. Rather, it should be viewed as a complementary technique which provides a valuable tool, stimulating interest and enabling a critical study of the dam. Accurate data gathering and regular interpretation of results are mutually reinforcing.

3. Selection of readings for automation

Data that are to be recorded can be limited to the most important parameters for the analysis of the dam behaviour.

In particular, they are as follows:

- the key parameters defining the state of dam loading and the surrounding conditions such as:
  - the water level of the reservoir and, if necessary,
  - temperature readings at selected locations,
  - several uplift pressure readings,
  - the rainfall;
- the principal parameters characterising the behaviour of the structure and its foundation such as:
  - deformation readings at key points in, or on, the structure,
  - seepage and drainage water discharges for concrete dams,
  - drainage water discharge and pore-water pressure readings for embankment dams.

Sometimes other measures can still be useful for following the behaviour of the structure and its foundation (by using, for example, extensometers, turbidity meters for the seepage water, etc.).

It is not recommended to record a vast number of readings which in principle only need to be taken relatively infrequently. An excess of readings can obscure the overall picture of the dam behaviour and can reduce the dam warden's motivation.

4. Methods to put automation into practice

In situations where the data characterising a state of loading or behaviour has to be transmitted over long distances and stored in memory it is important to adopt the following principles:

The sensors must be both simple and strong and capable of delivering reliable results in hostile environmental conditions.

The electronic sensors must be examined for electromagnetic compatibility (EMC).

Those sensors which are inaccessible, and consequently difficult to replace (such as temperature probes, deformation measuring devices in concrete or pore-water pressure gauges in the embankment and in the foundation) should be particularly protected against power surges. Ideally, these sensors should be redundant.

Where feasible, an automatic reading system must at all times be capable of being checked by a manual reading to avoid significant errors.

It must be possible to make simple adjustments to recover the original state once new parts have been installed.

The longevity of the supply of spare parts and the quality of after-sales service from suppliers must be guaranteed.

The number of sensors installed for a given parameter have to be sufficient such that the malfunctioning of one of the components does not endanger the continuity of the monitoring and inspection.

The transmission of data will be digitised. The analogue to digital converter must be as close as possible to the sensor, in a place that is accessible at all times.

Particular attention must be paid to protection against power surges (especially those caused by lightning) throughout the measurement chain.

5. Data processing methodology

If the data are processed by computer, the monitoring team must be able to access it at all times, preferably in the operator's control room. The dam warden or the staff on duty at the power station can examine the results daily using appropriate graphs or consult the graphs generated by the computer to assure themselves that there are no irregularities. By means of this complementary process of checking the results, the inspection personnel keep an eye on the behaviour of the structure, have an increased interest in the results and contribute, through the experience thus gained, to an improvement in the quality of the dam monitoring.

If a programme is available that is able to determine the limit values of the most important readings (taking account of the load and the seasonal effects) the manager can immediately check the credibility of the readings and let them repeat if necessary to confirm or correct them. This method of checking is efficient and reassuring for the operators.

In general, the short term checks by the dam warden or the site operators are enough to detect any unusual behaviour. In the meantime, the automatic sounding of an internal alarm in cases where the limit values are exceeded, allows for rapid detection of:

- a malfunction in the measurement chain and the transmission, or
- an accidental manual interference with a sensor (in particular the pendulum).

6. Surveillance programme

The use of database management programmes on a computer can lighten the task of surveillance for the dam owner (checking readings) and for the engineer charged with continuous monitoring (analysing results). It must also be borne in mind that the quality of the results will depend on the computational capabilities of the programmes employed. As the calculations are always carried out in the same manner, it is not inconceivable that through the use of inadequate algorithms one could fail to notice the progressive deviation of a reading which would not appear unless the database and the programme are sufficiently powerful to enable comparisons across an extended period.

Consequently, it is recommended that the programmes be tested periodically against known readings, and compared with already established results. When used with care, the computer is an important auxiliary aid to analysis and decision making.

7. Automation projects

A detailed project definition and specification for the introduction of the automatic recording and processing of a number of dam readings should be drawn up, preferably jointly by the owner of the dam, the engineer and the dam specialist responsible for checking the behaviour of the dam.

By proceeding in this way, the optimum choice of the parameters for recording and processing automatic readings and the appropriate match between the equipment selected and the method used to interpret the results are obtained.

8. Conclusions

Use of electronic and computer-based techniques in the monitoring of dams offers new methods of following the behaviour of dams across time and speeds up the inspection process.

The probability of early detection of an abnormal event is increased which in turn allows for the cause of the anomaly to be identified quickly and speedy remedial action to be taken. In addition, valuable time is gained should it prove necessary to take the preventive measure of lowering the reservoir.

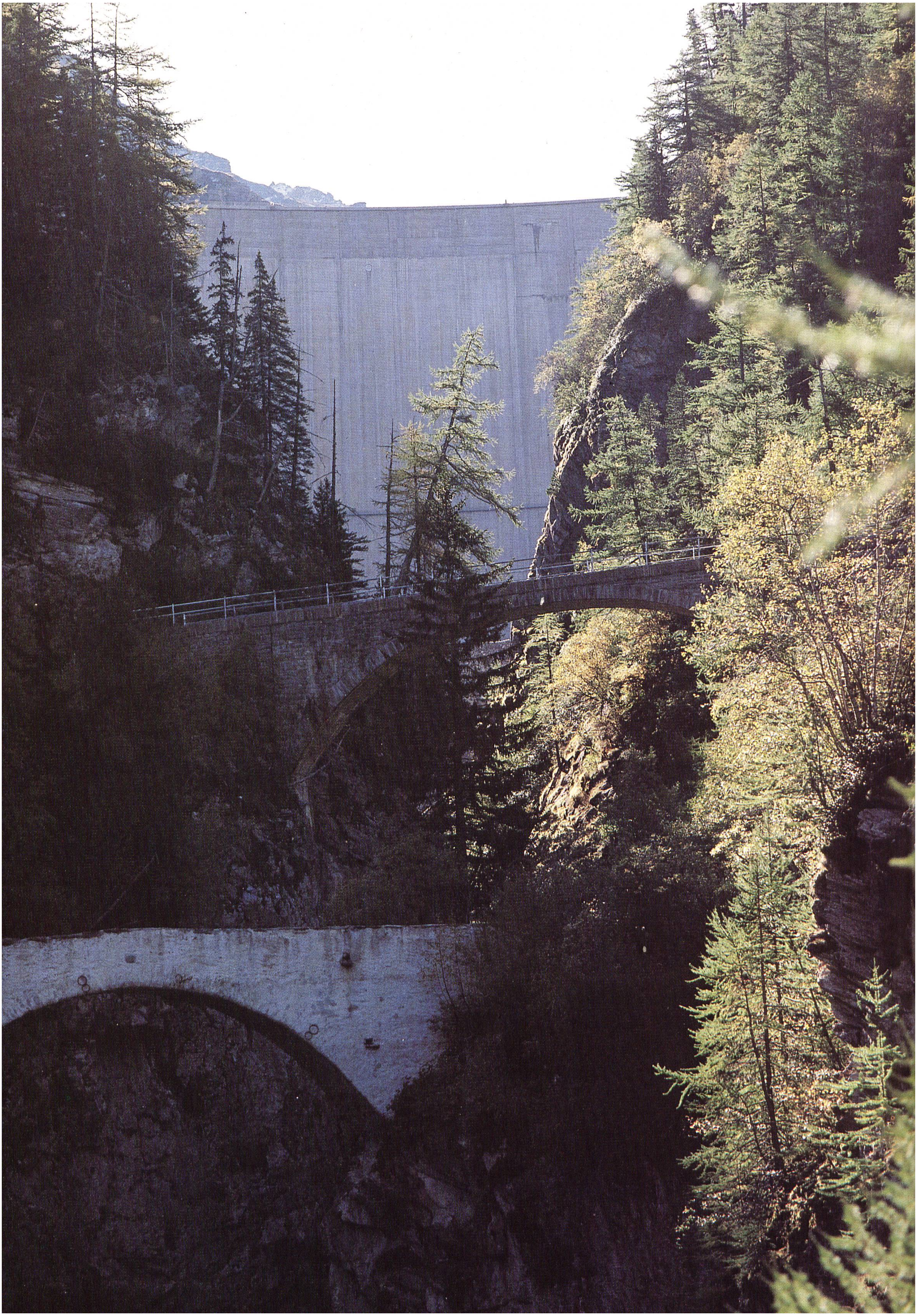
Furthermore, computerisation can reduce interruptions in dam surveillance when access to the structure is not possible, in particular due to inclement weather.

These advantages are only achievable if the most important parameters are recorded automatically, if they are transmitted to a permanently manned control room and the functioning of the principal elements of the system are guaranteed.

The use (even partial) of automation and computerisation can lead to marked improvements in the quality of monitoring without it being necessary to identify from the outset all the technical possibilities.

Next pages: The recently raised Mauvoisin dam is the highest arch dam of Switzerland (250 m).
(Photo: Mauvoisin Hydropower Company)

Lucendro buttress dam of Atel Hydropower Company on the St. Gotthard-pass. (Photo: *Jean Odermatt,* Eglisau)



The owner of the dam has to decide whether automation is justified and to what degree it needs to be taken after consultation with the engineer and the dam specialist responsible for the inspection of the dam behaviour.

In conclusion, the introduction of automatic reading and processing of some of the inspection data in dam surveillance does not change any of the principles applied beforehand which are:

- the regular visual inspections of the structure and its surroundings,
- the regular checks on the behaviour by manual recordings which have to be analysed and interpreted immediately.

The monitoring of a dam can be improved and intensified, the frequency of certain readings can be modified easily and their interpretation achieved almost instantaneously with the introduction of a well designed system. On the other hand it is unlikely to lead to a reduction in costs or personnel.

The introduction of these new techniques does allow for reductions in the time the dam operators dedicate to the work: a certain part of this time can therefore be spent on other tasks. Whatever the solution, the work of dam surveillance must always remain the top priority.

The capture and processing of readings Part 2: Possible applications

Working group for the monitoring of dams – 1993

1. Introduction

The partial report "The Use of Electronic-based Systems in Dam Surveillance, Part 1: General Concept, 1993," outlined the points which need to be considered when integrating electronic-based methods into the monitoring of dams. This second part complements the preceding document by describing how best to achieve these aims.

The advantage of an electronic-based system is that the results can be collected and transmitted continually, regardless of location. Attention can then concentrate on collecting the readings across time and transferring them to a centre which is continually staffed (or more regularly staffed than the dam itself).

In addition, surveillance can be carried out when access to the dam is extremely difficult due to bad weather or in the case of a high risk of avalanches. Remote readings offer a potential deployment of computing which can contribute to an improvement in the quality of monitoring. This immediately raises the crucial problem of identifying the readings which need to be included and the frequency with which readings need to be taken. This aspect is addressed in Section 2.

When large quantities of automatically generated data are to be stored in memory (which is inevitably the case) graphics and/or analytical software can make interpretation far simpler. The possibilities are presented in Section 3, including those relating to the behaviour in the short and long term. The development of software for the comparisons between measured values and calculated values is not addressed.

It is clear that computers will be used during the production of the reports containing the readings (and perhaps the dam expert's report) if the collected data are stored. That means, above all, that full use should be made of graphic presentations. The range of graphics possible, and those which are particularly suitable to the task, are presented in Section 4.

A large quantity of data are generated automatically and acquired almost continuously. The amount of data stored in the short, medium and long term must be strictly controlled so that neither too little nor too much is produced for the archives. The limited life of the media on which the data is written and the operating systems pose further problems. If the data banks are not recopied at regular intervals and, as far as possible, stored in archives in another form, there is a risk of permanent loss of data. These two aspects are covered in Section 5.

In addition to the data gathered automatically there are those gathered manually. The latter consist of measuring points which can only ever be collected manually and those which have automatic gathering devices. The means of transferring the data automatically to the computer system in the simplest and most reliable manner is discussed in Section 6.

Finally, in relation to the use of computers in dam monitoring there is the issue of guaranteeing surveillance in exceptional conditions, that is to say, in situations where the electronic equipment or the trained operators of the electronic equipment are not available. Thought should be given to ensure that manual measurements may be taken in the conventional manner without disruption. This aspect is covered in Section 7.

This report outlines the applications using only a relatively modest amount of computing. This is done in the recognition that the surveillance of dams is a task too important to be confined solely to automatic analysis. A totally automatic surveillance of the behaviour, where there is no human intervention except in cases where the established confidence limits are exceeded, is to be avoided as the controlling staff would not have sufficient experience in the operation and behaviour of the dam anymore. The other extreme, which consists in a total rejection of computing, is not generally a good solution either since there are real improvements in monitoring to be gained and report preparation may be simplified.

As is so often the case, the optimum solution lies in finding the middle way even though deviations from the mean may be justified depending on the requirements of each individual case. For example, a comprehensive electronic transmission system might be entirely appropriate for a dam which is extremely difficult to reach in winter. Conversely, no automation is perhaps justified for small structures located at moderate altitudes.

The objective of this report is to aid decision making and encourage discussion.

(This second part may be read independently of the first; a certain amount of repetition of the material is inevitable.)

2. Remote readings as an aid to monitoring

2.1 General statements

Taking readings remotely significantly aids the monitoring and control of a dam as long as the adopted solution is based on the requirements of the particular dam and provided the system meets the objectives.

There are a number of advantages in having the most important readings automatically gathered and transmitted to the control centre. In particular these include:

- The possibility of examining the most important readings at all times in order to assess the behaviour of a structure. This enables a more rapid detection of an anomaly and leads to quicker intervention.
- The possibility of following the change in the readings across time, since readings are gathered and stored on computer memory without interruption. As the frequency of the readings being gathered increases, the surveillance becomes almost continuous.
- The possibility of continuously comparing the measured values with the limit values determined on the basis of the loading conditions on the structure. If the limit states are exceeded it allows the cause to be determined immediately enabling a quick reaction, if necessary.

The readings transmitted electronically which are stored in the computer memory can be processed to provide presentations (in tables, graphs, etc.) contributing to a better understanding of the phenomena and their analysis.

In winter, in the case of heavy snowfalls and hence lack of access to the dam, the electronically transmitted readings can occasionally replace the manual readings.

At the time of flooding the build-up of the phenomenon in its initial phase can be tracked remotely. This enables those responsible to take the preliminary decisions concerning, for example, the application of the water-alarm procedures.

In order for the advantages to be fully realised, it is essential that readings transmitted electronically are extremely reliable and precise across time.

The remote transmission of certain information characterising a structure is a complementary element of surveillance security. It can not under any circumstances replace on-site inspections.

2.2 Readings for transmission

As a general rule, it is pointless to transmit readings from locations all over the structure. The transmission in real time of all information concerning the dam does not improve the security. In principle, only those readings which allow an easy evaluation of the normal or abnormal behaviour should be transmitted.

A careful selection must be made jointly by the owner of the dam and the dam expert taking into account the type of structure and the characteristic elements which govern its behaviour. Further readings can always be transmitted should a particular phenomenon arise in one part of the dam.

In order to carry out remote analysis of the behaviour of a structure as a function of the state of loading, and possibly the climatic conditions, the following information is generally useful:

a) General information for all structures

- the water level of the reservoir,
- the inflow discharge with a view to forecasting the rising water levels,
- the weather conditions: the rainfall because of its influence on drainage, the air temperature.

b) Gravity dams and arch dams

- the most representative dam displacements,
- the concrete temperature, if an analytical forecasting model is used,
- the characteristic seepage and drainage water discharges,

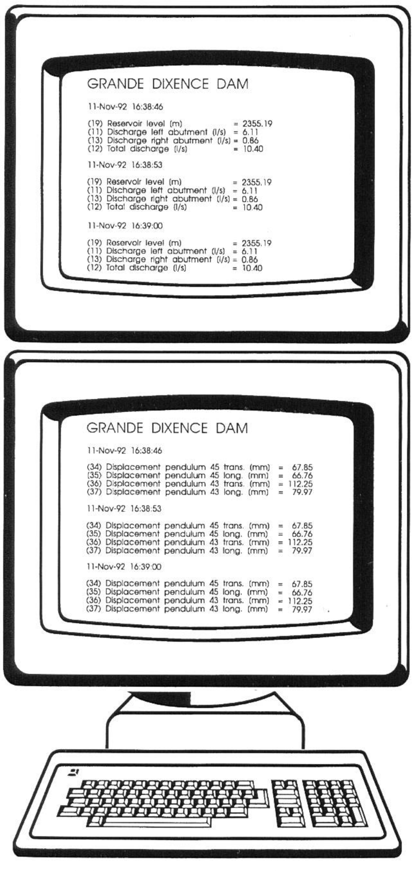


Figure 2.1. Screen-based output of instantaneous readings.

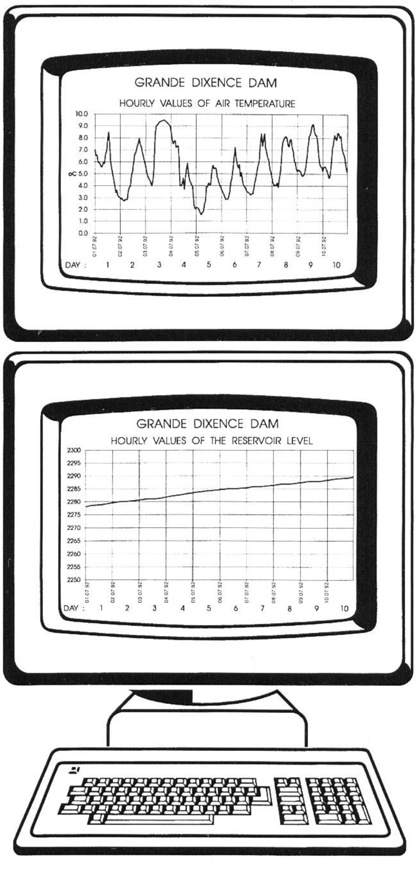


Figure 2.2. Short term data set – 10 days – readings every 15 minutes.

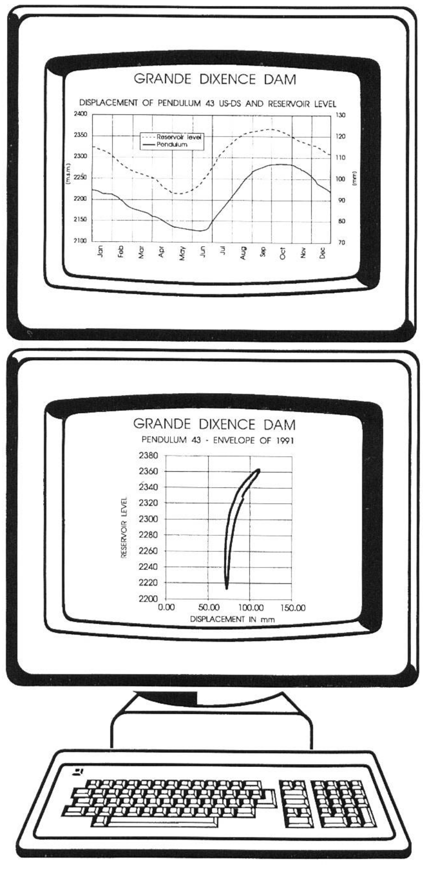


Figure 2.3. Long term data set of daily readings.

- some representative readings of uplift pressure (especially for gravity dams).

c) Embankment dams
- seepage and drainage water discharges from the most representative points in the body of the dam,
- some characteristic values of pore-water pressure,
- possibly the quality of the seepage and drainage water.

2.3 Rational use of electronically transmitted readings

It must be possible to visualise all the values continually arriving from the dam in real time (Figure 2.1.). With electronic transmission the values generally arrive continuously (or at a regular period of the order of one minute) at the control centre. The operator has to decide at what frequency the values must be recorded and how to store them. In principle, individual values at periods varying between one hour and one day are sufficient to analyse the dam behaviour. For security reasons relating to the electronic transmission system and processing, average values are generally recorded every quarter of an hour.

In principle, there are two types of data sets used for interpreting results:

a) Short term data set (Figure 2.2)
This file consists of the data transmitted electronically, and regrouped by appropriate processing by value every 15 minutes, for example. This enables a very detailed visualisation of a reading's evolution and possibly the correction of errors. The lifetime of this file is in the order of 5 to 10 days.

b) Long term data set of daily readings (Figure 2.3)
This file is made up of daily values: minimum, maximum, average, instantaneous. This allows a complete time cycle of a reading to be visualised. The file assists in monitoring the long-term behaviour of the dam. It will be sorted chronologically. The database will be supplemented by the manual readings and the checks on the automatically recorded values.

The fifteen minute, hourly and daily values are established from the average database values or by taking a single value at a precise time, for example at midnight. The choice depends on the rate at which each parameter changes.

All the processed readings must be presented in a clear, graphic format in order to allow an accurate, simple interpretation by the dam operators. Envelope curves and analytical models are useful tools to aid interpretation of the readings. An analytical model enables the limit values to be determined as a function of the loading state acting on the structure. It is possible to compare the instantaneous values with the calculated limit values automatically and in case of anomalies to react rapidly.

2.4 Staff training

The objectives of the automatic data capture system will be clearly explained to the dam wardens. Their role is further reinforced and given value by the systematic check of the measurement chain by their manual readings taken, in general, monthly.

The staff at the control centre will be equally well informed of the required objectives. These will be based on the operating instructions established at the time of installation of the automatic monitoring system.

2.5 Use by the experienced engineer

In principle, the engineer and the manager should have the same information and the same programme for processing the readings at their disposal. The experienced engineer can study the details of each reading and its change with time through a complete cycle. Anomalies would be the subject of detailed analysis. This information can be presented in the annual report on the behaviour of the dam, and the five-year inspection survey documents under the same heading as that of the manual readings carried out by dam wardens.

3. Aids for the analysis of the numerical data

The following general procedure is followed to analyse the readings:

- firstly, the readings are tested for credibility,
- after that, all the readings are tested and systematically processed to enable the different graphs and diagrams to be produced,
- for certain parameters, for example the dam displacements and deformations, the measured values may be compared with the values estimated by calculations.

These data must be analysed and evaluated as quickly as possible after the readings have been carried out. The ability to react rapidly must exist.

3.1 Checks on the credibility of the data

Credibility tests on the readings defining:

- the state of loading on the structure (date, level of the reservoir, air, water and concrete temperatures, rainfall), and
- the behaviour of the dam and its foundation (movements, strains, changes in length as well as uplift pressures, water pressures in the pores and rock joints and seepage and drainage water discharges) can be carried out either before or after the data is transferred to the computers.

These checks consist of comparing the values obtained against those recorded earlier and evaluating if the former are plausible, taking account of the different state of loading on the structure. In case of doubt, a comparison must be made with the results obtained under comparable loading states during the preceding years.

In cases where these checks reveal nothing unusual, the results may be stored on the computer. In the light of dubious values, or those out of the ordinary, it is essential to inform the owner of the dam immediately and to ask for the readings to be retaken. Very often such checks appear to be the result of mistaken readings, especially when only a single value appears doubtful. From time to time these checks also uncover the malfunctioning of some recording equipment which enable steps to be taken to eliminate the faults.

The results once checked, and possibly corrected, are then entered into the computer with a view to processing and storing before being finally printed-out in tabular form.

The tables in Figures 3.1 and 3.2 present in chronological order the pendulum readings from Moiry Arch Dam as well as the parameter values determined from these (in the example shown, the radial displacements). Tables such as these may also be incorporated in the annual report, as required. The latter contribute to the preservation of data in the long term.

PENDULUM READINGS

MOIRY DAM CONTROL YEAR 1991

PENDULUM : Upstream-downstream readings (mm)

Reading nb :	1	2	3	4	5	6	7	8
Date :	8.01	4.02	4.03	8.04	13.05	5.06	1.07	5.08
Water level :	2230,28	2215,36	2197,46	2180,58	2152,57	2163,30	2196,54	2233,66

READING STATION

PENDULUM 12								
G5 2242,90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G4 2224,90	67,75	67,60	67,70	68,30	69,50	70,10	70,50	71,35
G3 2206,90	53,00	53,50	53,95	55,45	57,35	58,70	59,45	60,10
G1 2167,90	41,20	45,10	48,75	53,25	57,00	59,90	59,35	53,30
G1 2128,90	93,80	87,10	80,60	73,30	66,90	64,05	68,25	80,80

PENDULUM 15								
G5 2242,90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G4 2224,90	56,50	56,50	56,65	56,00	54,80	54,30	53,85	53,10
G3 2206,90	65,40	64,90	64,50	62,90	61,05	59,50	58,80	58,30
G2 2167,90	47,85	51,95	55,80	60,50	64,60	67,70	66,80	60,40
G1 2128,90	28,85	37,40	46,45	56,10	64,85	68,15	61,35	44,30
GP 2107,90	21.10	31,20	42,10	53,40	64,30	67,50	58,15	37,05

PENDULUM 18								
G5 2242,90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G4 2224,90	60,20	60,10	59,75	59,10	57,90	57,45	57,10	56,80
G3 2206,90	63,85	63,00	61,90	60,00	58,15	56,90	56,45	56,90
G2 2167,90	67,50	62,65	57,60	52,35	48,30	45,65	47,10	55,60
G1 2128,90	93,20	85,40	77,10	69,10	62,20	59,55	65,45	81,00

Figure 3.1. Pendulum readings in radial direction.

PENDULUM DISPLACEMENTS

MOIRY DAM CONTROL YEAR 1991

PENDULUM : Upstream-downstream displacements (mm) (+) = downstream

Reading nb :	1	2	3	4	5	6	7	8
Date :	8.01	4.02	4.03	8.04	13.05	5.06	1.07	5.08
Water level :	2230,28	2215,36	2197,46	2180,58	2152,57	2163,30	2196,54	2233,66

READING STATION

PENDULUM 12 (Reading station at el. 2128,90 considered as fix point)								
G5 2242,90	43,30	36,60	30.10	22.80	16.40	13.55	17.75	30.30
G4 2224,90	35,60	28,68	22.22	15.45	10.15	7.87	12.54	26.03
G3 2206,90	29,66	23.31	17.09	11.12	6.43	4.92	10.00	23.45
G1 2167,90	15.54	12.22	8.86	5.58	2.46	2.40	6.44	13.89
G1 2128,90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

PENDULUM 15 (Reading station at el. 2107,90 considered as fix point)								
G5 2242,90	68.00	57.90	47.00	35.70	24.80	21.60	30.95	52.05
G4 2224,90	59.85	49.75	38.70	28.05	18.35	15.65	25.45	47.30
G3 2206,90	52.50	42.90	32.40	22.70	13.65	12.00	22.05	43.65
G2 2167,90	35.00	29.00	21.95	15.35	8.55	8.45	16.90	31.60
G1 2128,90	10.15	8.60	6.75	5.10	2.95	3.05	5.60	9.65
GP 2107,90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

PENDULUM 18 (Reading station at el. 2128,90 considered as fix point)								
G5 2242,90	48.30	40.50	32.20	24.20	17.30	14.65	20.55	36.10
G4 2224,90	40.50	32.79	24.74	17.30	11.41	9.17	15.43	31.33
G3 2206,90	34.03	26.91	19.51	13.09	7.81	6.24	12.68	28.08
G2 2167,90	18.39	14.83	10.87	7.40	3.88	3.57	8.52	16.86
G1 2128,90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 3.2. Radial displacements of the pendulum using readings from Fig. 3.1.

3.2 Graphic interpretation of the results

Graphs and diagrams have always been used in the evaluation of results in dam observation. However, computer technology now enables these results to be presented easily and quickly both on the screen and on paper. This processing of readings also provides a second and more accurate check on their credibility.

The two following types of diagrams are often used for representing deformations, uplift pressures and discharges:

- Representation of a value or group of values of a parameter as a function of time: for example Figure 3.3 represents the radial displacement of the Moiry Dam observed from points sited at different pendulum heights.
- Representation of a value or group of values as a function of the level of the lake: for example Figure 3.4 represents the radial displacement of one of the points shown in Figure 3.3 in comparison with the measurements of the previous year together with the range of displacements observed across the previous five-year period.

The two types of diagram allow a simple assessment of whether or not the measured values lie within the normal range:

- on the one hand with reference to the previous readings, that is to say in the short term, and
- on the other hand with regard to the older readings over a longer period, that is to say in the long term.

The first type of diagram, covering one or several years, enable checks to be made to see if the values vary uniformly in a fixed range, or conversely, if the values jump or show a tendency towards an unusual growth or diminution.

The second type of diagram offers a check if the change with time of a given value is a regular function of the water pressure acting against the dam and if the values lie within the range of values observed in the previous five-year period. In the case where this value moves outside the range over a period of time (on one side or the other) it indicates that the parameter in question exhibits a long term tenden-

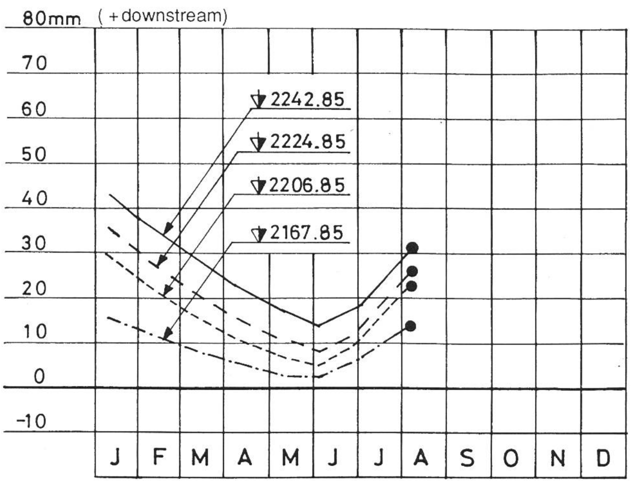


Figure 3.3. Upstream-downstream displacements at four measuring points along the length of the pendulum as a function of time (values taken from Fig. 3.2).

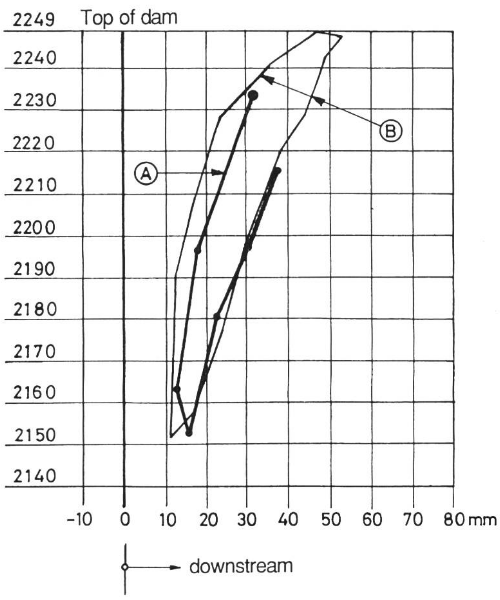


Figure 3.4. Upstream-downstream displacements of a point on the pendulum as a function of the reservoir level
(A) Current year (values taken from Fig. 3.2)
(B) Envelope for the five-year period 1984–1988.

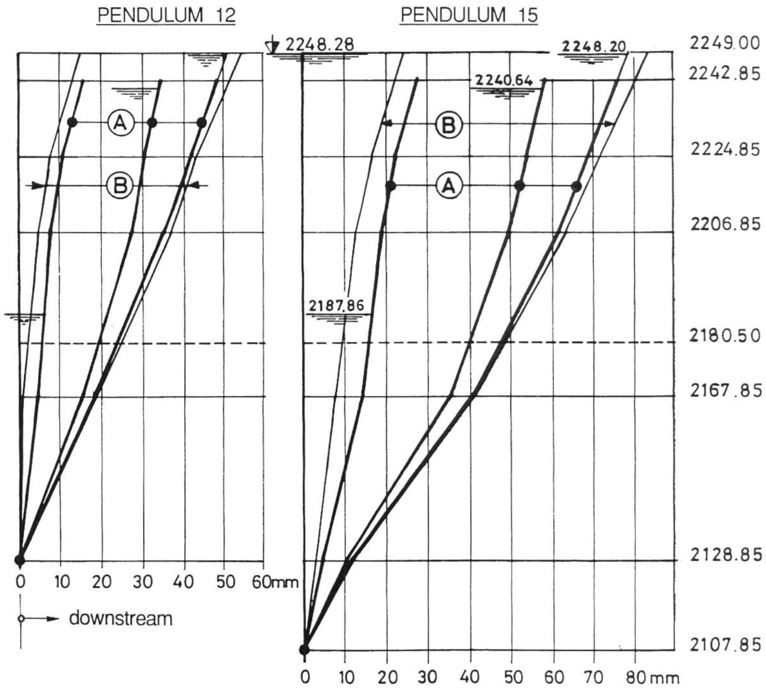


Figure 3.5. Upstream-downstream deformations along the length of the pendulum at two transverse sections of Moiry Dam.

(A) Deformations for the current year
(B) Envelope for the five-year period 1984–1988.

cy either to growth or to diminution which requires an explanation. In the case where only several isolated values are to be found outside the normal range, it is necessary to examine if these resulted from an unusual state of loading (level of the lake and temperature).

Another example for evaluating the deformations is given in Figure 3.5 representing the deformations observed along the length of a pendulum. This allows:

- to check if the deformations shown are credible and if these develop uniformly following variations in the loads acting on the dam,
- to see if the deformations are to be found in the range of the previous five-year period,
- for rapid comparisons if needed, with the deformations observed under similar loadings in order to decide if a somewhat unusual deformation can ultimately be considered as normal or otherwise.

The uplift pressures, seepage water and drainage water discharges in combination with the level of the lake, are often represented as a function of time. As an example, Figure 3.6 shows the uplift pressures under the Naret 1 Dam. It is interesting to note in this diagram that the uplift pressures, from January to August vary more or less proportionately with the level of the lake and that after that date they drop abruptly. This sudden fall in pressure follows on from the drawdown associated with the drilling of drainage boreholes near the pressure points. In Figure 3.7 the same results are given in percentages of the static pressure (of the lake) as a function of time and the level of the lake. Practically all the uplift pressures from January to the start of August lie within the range of the preceding five-year period. But after August the pressures are noticeably smaller and logically lie outside of the usual band.

Some final remarks on the subject:

- The diagrams shown are clearly not only useful for on-screen analysis but also for printed output (if possible in colour) to illustrate the text in the annual report containing the readings.
- Today, the graphs are generally produced by in-house programmes. In the future, standard programmes which can be adapted for different dams will become more readily available.

To use these attention must be drawn to the following:

- The programme must be easy to use.
- It is imperative that the user can select the scale. The programmes which automatically fix the scale on the

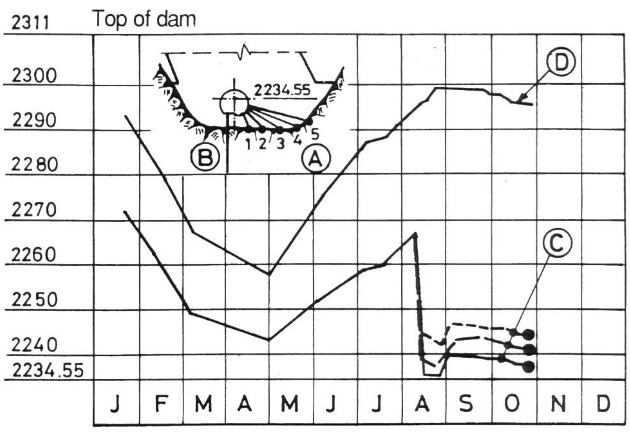


Figure 3.6. Uplift pressures observed at the toe of Naret 1 Dam as a function of time:
(A) Location of the pressure points 1 to 5
(B) Grout curtain
(C) Pressure points 1 to 5 (reduction in pressure during August following drawdown caused by drilling drainage boreholes)
(D) Reservoir water level.

basis of the range of a group of values are totally inappropriate for the simple reason that the values, across an extended period cannot be compared against each other if different scales are used.

- It must be capable of presenting two or three different diagrams on a page in order to compare the different parameters against each other.
- It is vital that the programme allows clear labelling of the diagram.
- The screens, plotters and printers must have a sufficiently high resolution to produce good quality diagrams.
- Finally, it is a great advantage to be able to reproduce diagrams in different colours. The ability to meet the various exacting requirements of the presentations currently stretches the limits of existing hardware and software.

3.3 Evaluating readings with the aid of an analytical model

Under normal circumstances graphs of the measured data enable a simple and safe check to be carried out on the behaviour of a dam. Nevertheless, certain doubts with respect to the safety may appear occasionally because the parameters characterising the behaviour exceed their typical values, for example following a prolonged period of abnormal weather or a change in the way the reservoir is managed. For this reason the desire to check the measured values against calculated values has increased in recent years. With reference to the comparisons, the following two possibilities are offered:

One consists of factoring the measured displacement by a correction obtained with the aid of a simple model in order to bring the effective state of loading on the dam to the same as the reference state of loading at which the level of the lake and the temperature are fixed. The factoring formulas may be obtained either using a deterministic or a statistical basis.

If the behaviour of the dam were truly linearly elastic, and furthermore, if the established formulae used to factor the values were absolutely accurate, the factored displacements calculated for each measurement would all give a single fixed value which is clearly not the case. In practise, it is always possible to establish the factored displacements from an individual reading, an average value as well as a credible range for the year. It will then be enough to confirm if the values calculated during the year lie within the pre-determined range.

It is clear that the simultaneous representation of these values, calculated at several points on the dam (such as those for Moiry Dam as shown in Figure 3.8) can further add to the reliability of the evaluation.

The other possibility consists of comparing a measured displacement against a displacement calculated by analysis and to examine if the difference between the two values lies in an acceptable range (even in extreme cases, if possible). One such example is shown in Figure 3.9 for the displacements of Santa Maria Dam.

The complexity of analytical models which determine the estimated displacements can vary enormously from one dam to another. If possible, the model should be of a deterministic nature and consider the effective load on the dam. Secondary effects, such as the seasonal movements of the valley sides, should also be considered through simple correlations.

Similar calculations, checking the uplift pressure and the seepage and drainage water discharges are also possible.

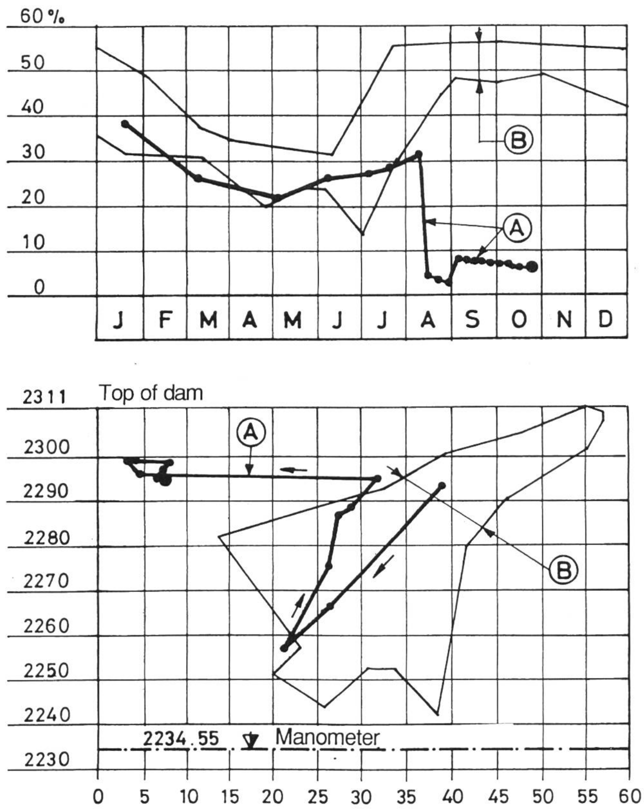


Figure 3.7. Average coefficient of uplift pressure in a transverse section of Naret 1 Dam
- Upper figure: as a function of time
- Lower figure: as a function of the reservoir level
(A) Current year
(B) Envelope for the five-year period 1981–1985.

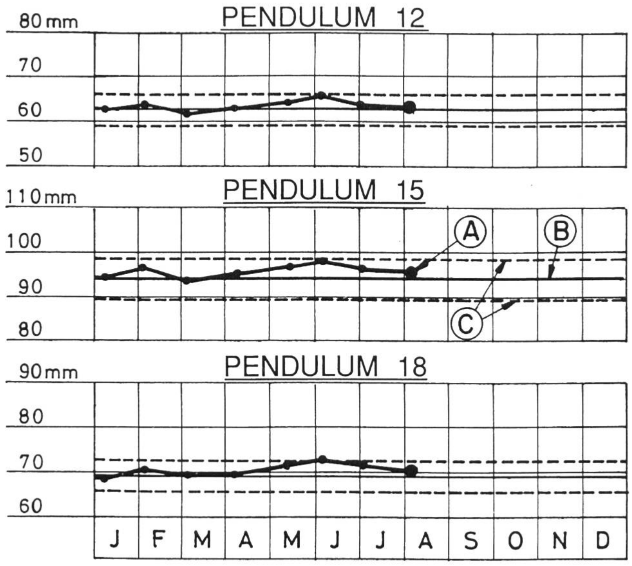


Figure 3.8. Upstream-downstream displacements of selected points, measured by the pendulums and factored for a fixed state of loading, compared with the reference values (which are constant for a particular reservoir level and temperature)
(A) Values calculated from the readings
(B) Reference values = average for the preceding five-year period
(C) Credible range of values for the current year.

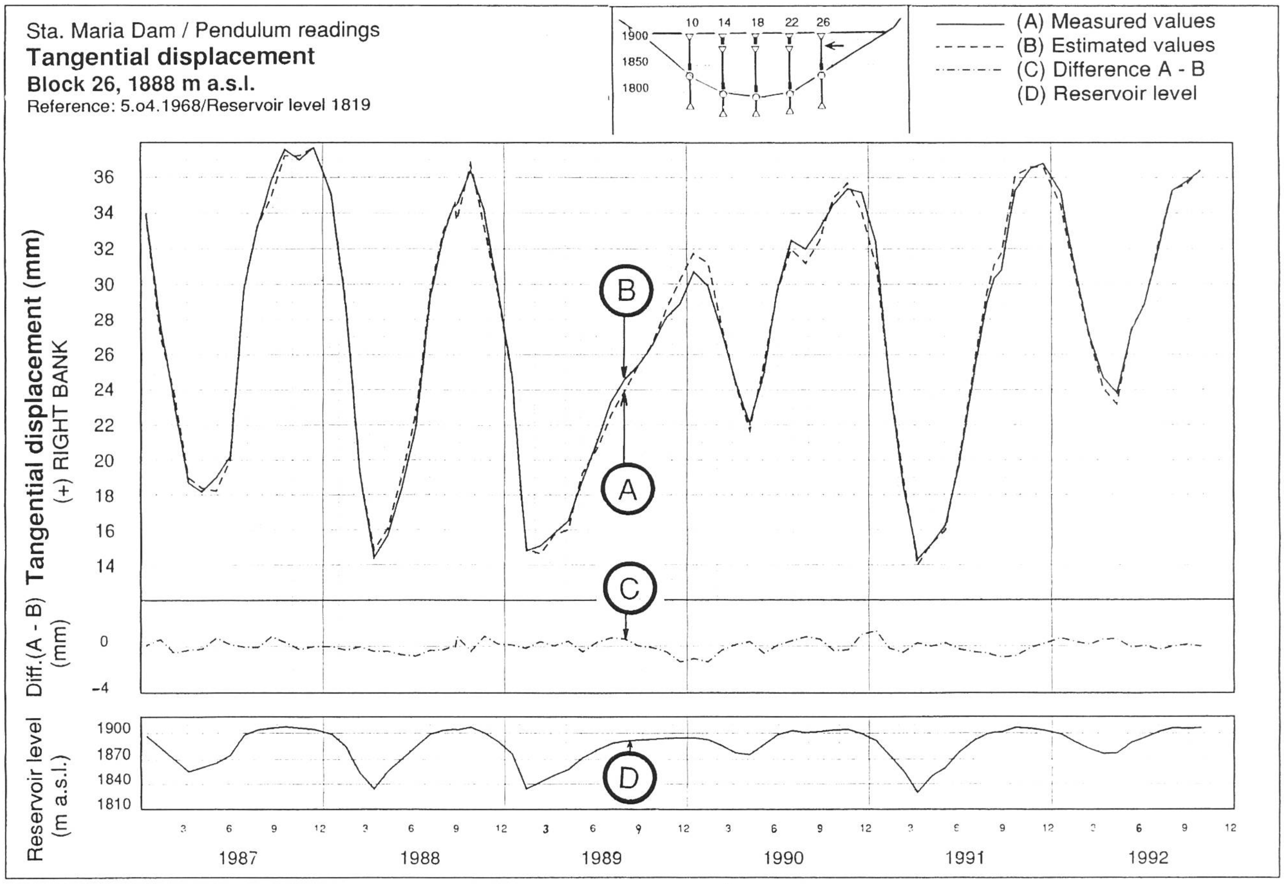


Figure 3.9. Tangential displacement measured from a pendulum reading. (A) Measured values. (B) Estimated values. (C) Difference between values. (D) Reservoir water level.

3.4 Final remarks

The introduction of computers into the analysis of the readings does not result in a fundamental change in the inspection procedures. As always, these checks are carried out by the engineer in charge and his collaborators. The equipment does not relieve him of the decision-making process. Only the engineer is able to decide if the dam is behaving normally or not. In the case where an anomaly has been noticed, the owner of the dam must immediately inform the Federal Office for Water Resources, the Canton and the dam expert.

4. Assistance with the production of the annual report

In the annual report containing the dam readings, those results which are essential for evaluating the dam behaviour are globally presented.

The graphs, and in exceptional cases the tables, in the report are of particular importance because on the one hand they illustrate the text written by the engineer and on the other hand they allow everyone to undertake their own analysis. The presentations employed must therefore be oriented towards these two objectives.

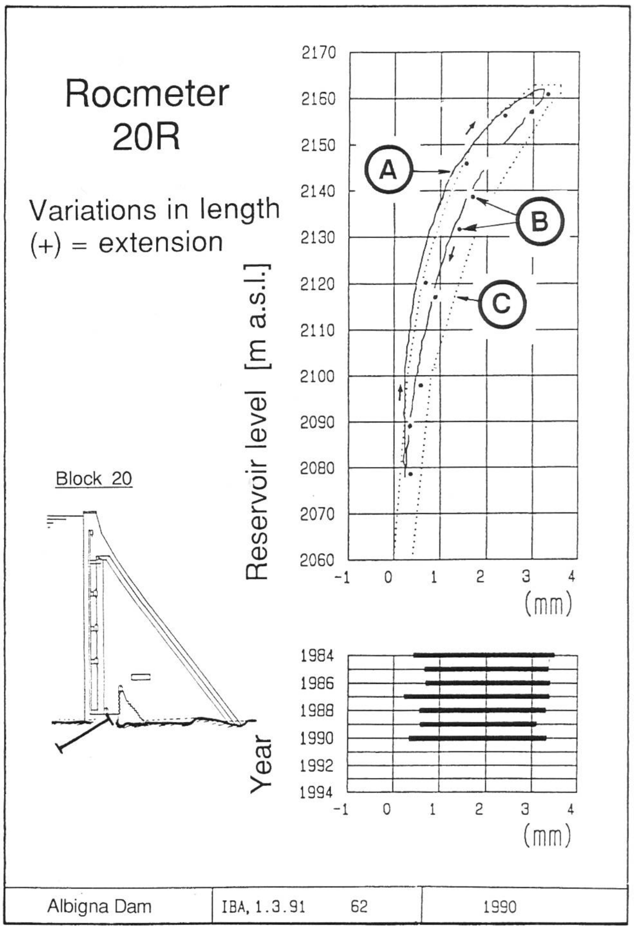


Figure 4.1. Variation in the length of a section measured by means of an extensometer in the rock foundation of a gravity dam. Above: as a function of the reservoir water level; below: yearly minimum and maximum values.
(A) Automatic reading
(B) Manual reading
(C) Envelope for readings from 1982–1987.

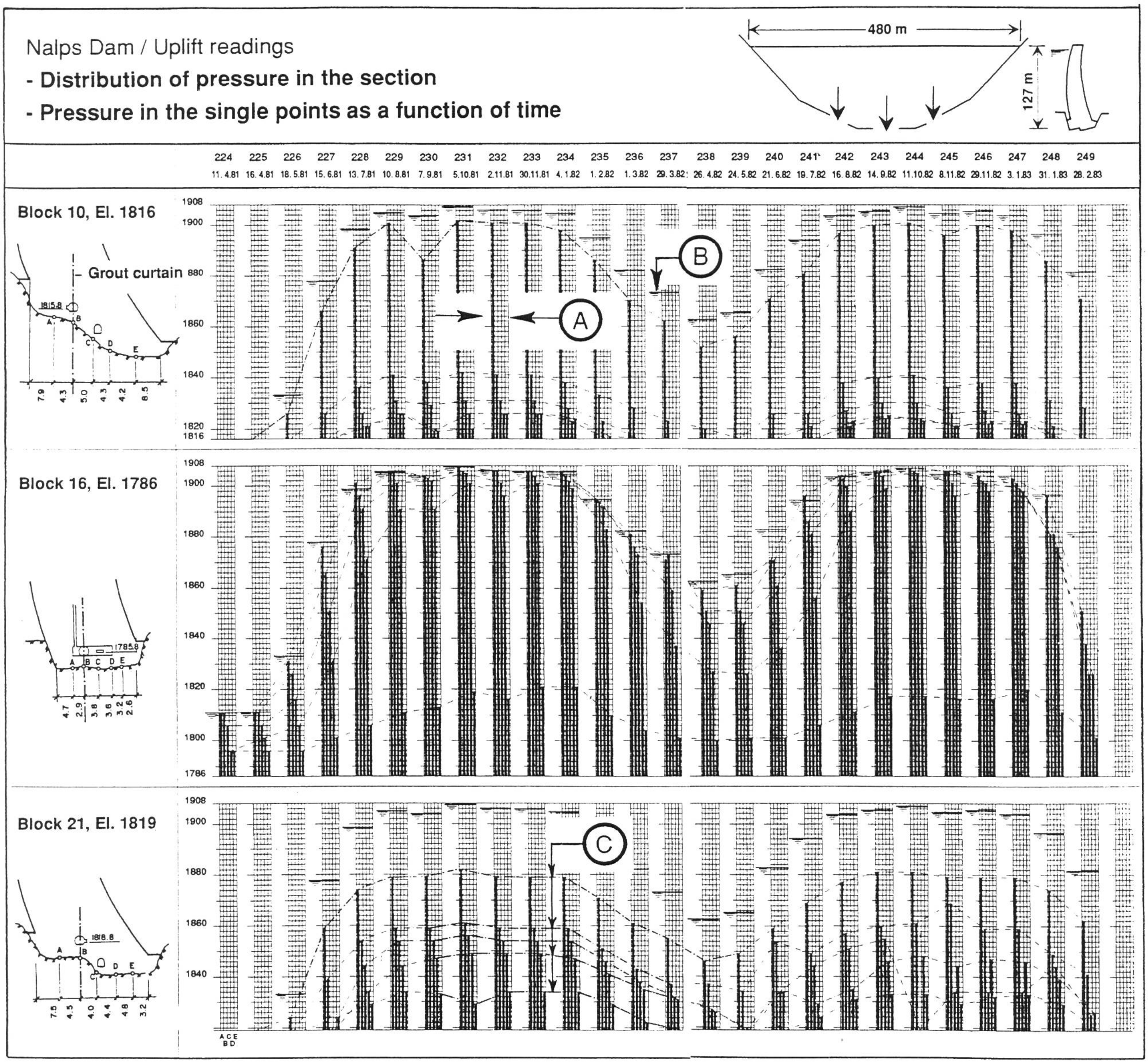


Figure 4.2. Uplift pressures from three sections of an arch dam. (A) Distribution of pressure in the section (bar diagram). (B) Reservoir level. (C) Uplift pressures as a function of time.

Due to the fact that the yearly report containing the readings must give a complete overall view on the behaviour of the structure during the year of the report as well as during the previous operating period, the presentations which are used for the current inspections are not given the same emphasis (Section 3). For the ongoing inspections, graphs and/or analytical models are needed to determine if the value of a parameter which has just been measured conforms to normal behaviour or indicates abnormal behaviour. For the check on the readings, it is important to be able to compare current values with those of similar periods over the preceding years.

For the annual report it is the change with time throughout the year which is of particular interest; this change can perhaps be compared with the envelope curves and/or those of previous years (Figure 4.1) if the latter are available. In this way, the effects of extraordinary loading (for example, due to an unusually low reservoir level during the spring) or any abnormal tendencies in the behaviour can be detected.

Where computers are used the database must be organised in such a way as to enable the ongoing checks on behaviour to be made independently of whether or not the readings are taken automatically and transmitted to a remote monitoring centre. This being the case, it is always advisable to also make use of the computers during the production of the report even if different graphs are required for the current inspection and the report.

The ease with which graphics and tables can be generated must not result in too many figures and listings being incorporated in the report such that the overall picture is obscured. To this end, it is recommended that different graphical formats be tested across several years to discover which work the best.

Several examples are shown in Figures 4.1 to 4.4. These share the following characteristics:

- they not only represent the values of the parameters in the year of the report but also those of previous years,
- the long term behaviour is represented, preferably from the date the reservoir was first in service,
- they also contain other parameters which are important in the understanding of the behaviour.

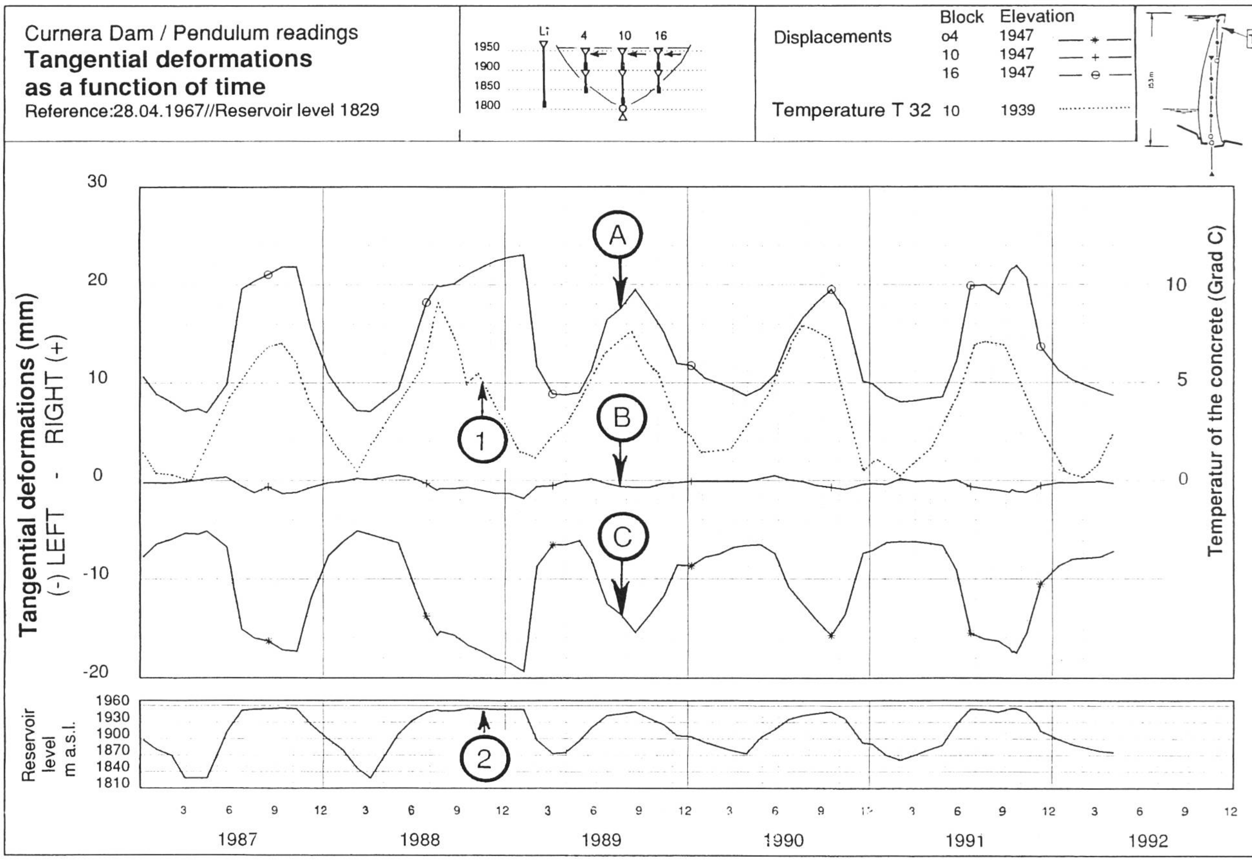


Figure 4.3. Tangential deformations at the crest of an arch dam measured from the pendulums as well as the loading parameters: temperature of the concrete and reservoir water level. (A) Deformation at the left abutment. (B) Deformation at the centre. (C) Deformation at the right abutment. (1) Temperature of the concrete (2.5 m from the downstream face). (2) Reservoir level.

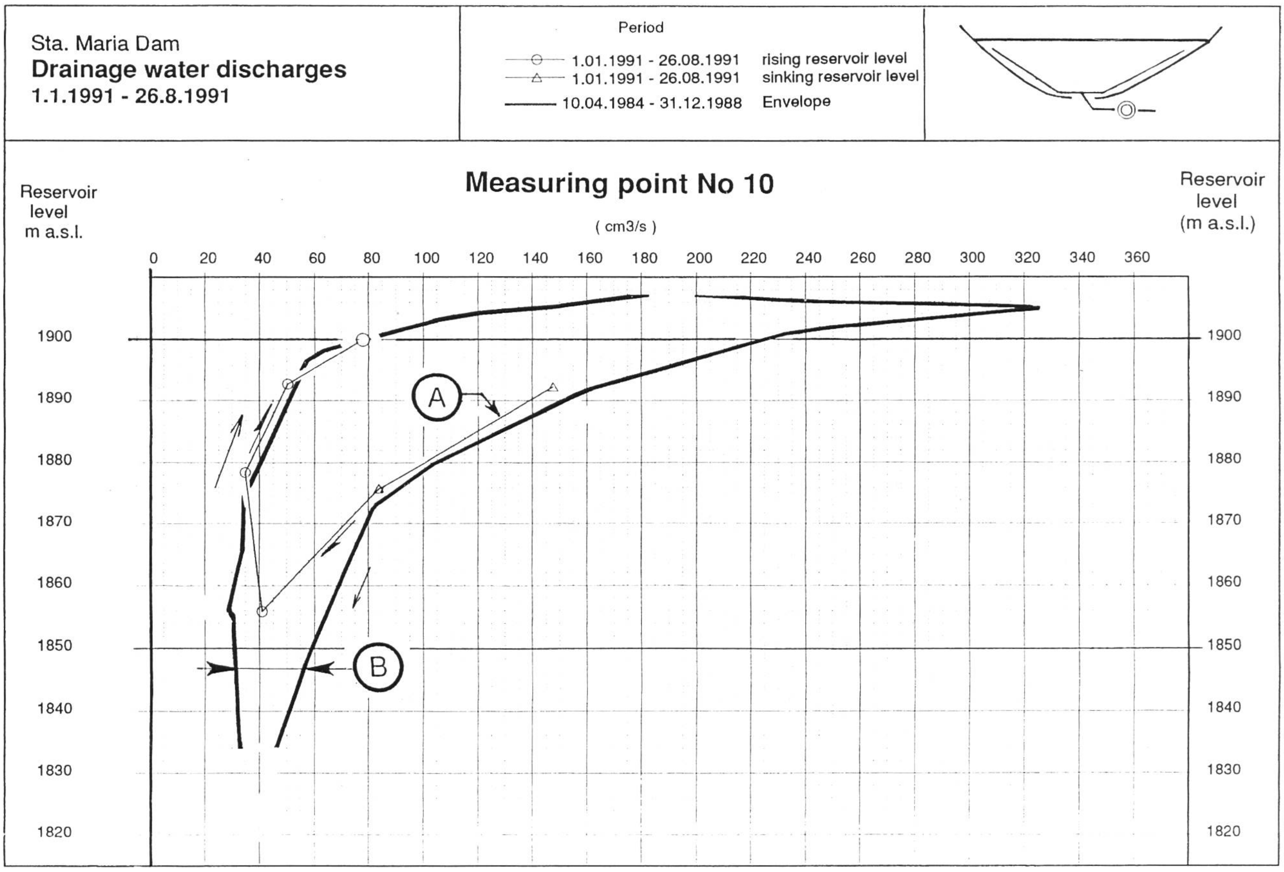


Figure 4.4. Seepage and drainage water discharges of an arch dam. (A) Current year. (B) Envelope for discharges for the preceding five-year period.

5. Archiving data

5.1 Storage

The aim of the archives is to create a database which can be accessed as needed. The first stage in the storage process consists of evaluating the needs and of selecting the data to be stored accordingly. Then the form of the data storage needs to be established, together with an assessment of how long they are to be stored for and the degree of reliability required.

The principles of storage are shown in Figure 5.1. In the first stage a reading is made, checks carried out on its credibility and then, according to need, it is transferred (by example from the memory of the bar-code reader into the memory of the personal computer).

This happens relatively frequently and a first stage archiving can be carried out at this level. In the second stage the data (or some of the data) are processed. This results in supplementary data which may also be archived. Processing of automatic readings is generally carried out less frequently than the readings themselves. This cycle of processing data/generating new data/archiving the data can repeat itself many times.

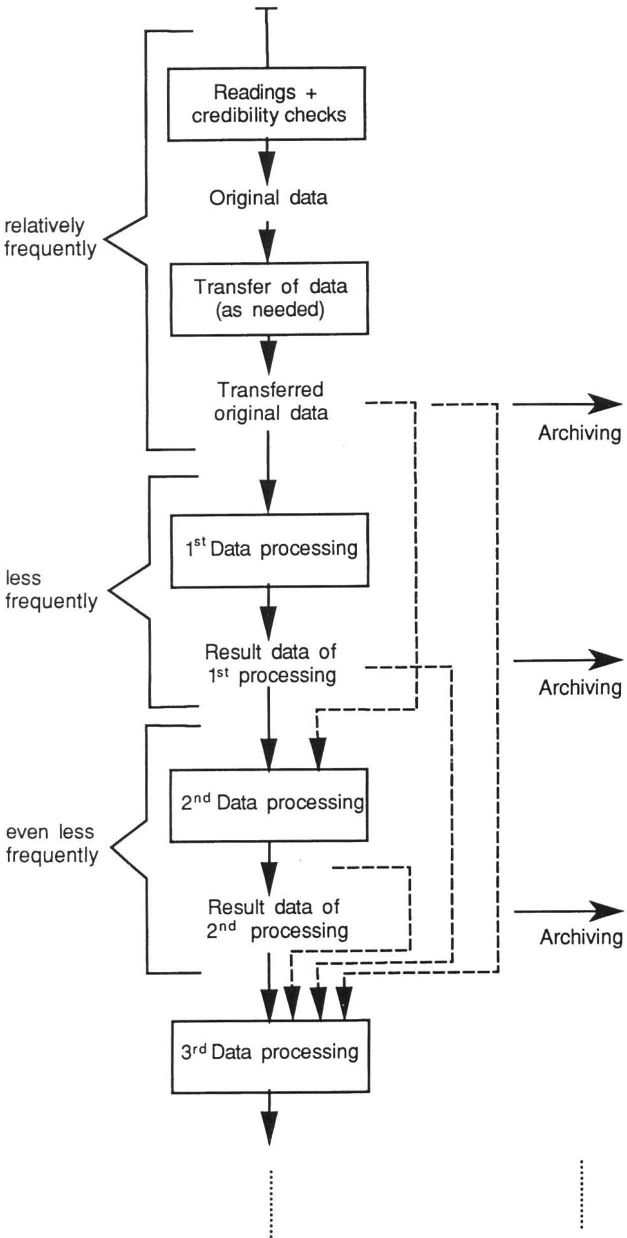


Figure 5.1. Principle of the measurement chain.

There are three fundamental problems related to archiving:

- *the quantity of data:* large amounts of data could accumulate and supplementary data could be generated in the course of the interpretation phase,
- *protection against data loss:* once archived, the data needs to be protected against loss and illegibility in the long term,
- *database management:* the archived data once protected against loss needs to be accessed reliably, completely and efficiently.

These three problems are discussed below.

5.2 Quantity of data

The introduction of automatic readings and continuous working has meant that data is generated with much less effort than before. Huge quantities of data can be easily acquired.

The original data is further processed in the course of successive manipulations creating yet more data. *Ad hoc* archiving of this accumulated data (original, interpreted, manually gathered, automatic) can pose insurmountable problems for database management and it is necessary to reduce their volume.

The need to judge the long term behaviour of the dam means that it is not possible to just simply erase old data as new data becomes available. Nevertheless, a reduction in data is possible by adopting the following measures (also see Section 2):

- archive average daily values and/or extremes rather than individual readings;
- archive readings drawn from a particular day of the week, and
- archive extreme values for specific periods and intermediate values.

With the establishment of strategies for reducing data it is important to keep original data (without erasing interpreted data totally). In this way, complete flexibility is preserved allowing later processing and manipulation of archived data, for example as better mathematical models become available.

5.3 Protection against loss of data

Storage can take various forms, such as magnetic tapes, video 8 cassettes and floppy discs. Loss of data can occur with all these forms through:

- total destruction of back-up media,
- deterioration of the back-up media,
- modification/alteration of the data, and
- existing hardware/software required for reading the data becoming obsolete.

Total destruction of back-up media: The total loss of back-ups can be avoided to a certain extent by placing the back-ups (magnetic tapes, floppy discs) in appropriate places with controlled access in fire-resistant filing cabinets. However, total protection is difficult to achieve and it is recommended that copies of the original archives be stored in different places (this is also important for other reasons, see below).

Deterioration of the back-up media: Few of the back-up media can completely satisfy the constraints of long-term storage with the possible exception of WORM (Write Once Read Many) laser discs. Copies need to be made periodically of all magnetic media in order to prevent loss of data.

Modification/alteration of data: Archived electromagnetic data can be easily altered or erased. A modification in the data can be premeditated (malicious damage) or accidental (alterations due to the electromagnetic field, poor handing). A protection against malicious alteration can, to a certain extent, be achieved by limiting access to the data (controlled access at the site, passwords for entry onto computers). Protection against accidental modification can only be achieved by taking back-up copies regularly and storing the copies in different locations. In particular, data relating to dam surveillance should be kept both by the dam superintendent (electrical company/operating company) and the engineer responsible for checking the structure.

In case of data processing (for example in the case of special studies) it is better to use back-up copies specially prepared for this purpose rather than the archival back-ups. The original archives should never be used for any purpose other than making new back-ups.

Existing hardware/software required for reading the data becoming obsolete: The storage process depends on the machinery and software employed. Potential problems arise with the transfer to a new machine (for instance, a new type of computer and/or operating system) and/or software. In these cases a systematic modification of all existing archives is necessary. This applies also to existing back-up copies, respectively new back-ups must be prepared.

Paper and film media: The use of scanners (connected to a personal computer) and text recognition software will soon allow the short-term recovery of data stored on paper back into the computer. It will then be soon possible to abandon computer based archives in favour of paper archives if the quantity of data is limited.

In order to control the accuracy of numerical data when it is transferred by means of scanners, a check sum (arithmetic calculations) can be established for each table archived. For example, this check could be the sum of all cell values.

When large quantities of data need to be archived the COM (Computer Outputs on Microfiche) system can be used. The archive files are prepared by software and the contents transferred onto a durable film.

Back-up copies: Having transferred the original data onto the computer, the following concepts can be applied to establish back-ups, for example:

- incremental daily copies (saving files modified during the day);
- complete copies of the memory bank at the end of each month;
- annual copies.

5.4 Database management

Appropriate archive database management demands a structuring of the data, for example chronologically or by grouping similar readings. It is particularly important to have an index in order to rapidly locate an individual data item. Where microfiches are used to store data, a reference index must be present on the microfiche itself.

It is also necessary to identify the meaning of the data, for example by reference to engineering drawings, types of instrument, modifications made to the measuring system, formulae for conversion or any other necessary information for a complete identification of the data. All this information also needs to be archived.

A control on the use of the archives must also be implemented (checks on entries and withdrawals).

5.5 Conclusions

In order to establish an efficient archival system it is necessary to determine the needs of the database, to set up the database according to these requirements and to identify the data that needs to be stored.

The archives themselves must be organised on the basis of a clear concept. The following fundamental points need to be addressed:

- the type of storage device (electronic media, microfiche, paper, etc.),
- redundant and decentralised archives under the control of the dam owner (electric company/operating company) and the engineer in charge of the dam,
- archiving original data and original documents,
- reliability in the long-term; durability and readability over several years (ageing, standards),
- spatial aspects (control of access, fire protection, archive cabinets),
- archive system, inventories, and
- security management of the archives (checks on entries and withdrawals).

6. Manual readings and computing

6.1 Introduction

For a number of decades the procedures involved in capturing and processing the parameters which characterise the behaviour of a dam has changed little. The recording of measurements was followed by manual transcriptions, calculations and rewrites such that possibilities for errors were introduced at each stage.

Errors in the measurements and their processing constitute the main elements which undermine the reliability of dam monitoring; improvement in dam surveillance is closely tied to the quality of the data which enables an analysis of the dam behaviour to be made.

To this end, different technical methods and rigorous procedures have been put into operation; electronic-based systems and more recently computers have contributed greatly to these improvements.

This section presents a concept of integrating field-based electronic systems into the process of dam surveillance by the operators.

6.2 The problems

How is it possible to improve the reliability of the total process of taking physical measurements on the dam, from their gathering by the operators through to their analysis by the engineers or dam experts (Figure 6.1)?

Without going into fine detail we shall review some causes for measurement errors:

- malfunction of the sensors,
- malfunction of the measuring equipment,
- error in identifying a reading,
- error in reading by the operator,
- error in transcribing the reading,
- error in the calculations,
- error in computer-based data gathering system,
- etc.

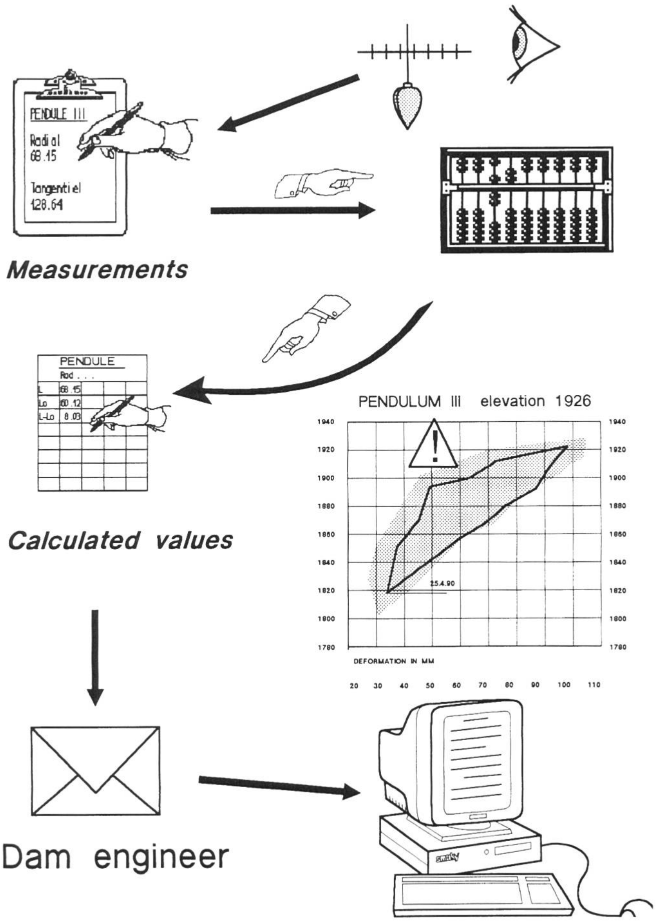


Figure 6.1. From the eye of the dam warden to the analysis by the engineer: the lengthy measuring chain.

These errors lead to difficulties in interpreting dam behaviour, resulting in dubious, mistaken or even totally false interpretations.

6.3 The objectives

Computing can reduce the risks of errors and eliminate certain causes. To this end, this new method of dam surveillance has to have the following objectives:

- improve the reliability of readings,
- ease the tasks of those taking the readings,
- ease the capture and processing of the readings.

These are dependent on the following conditions:

- the measuring equipment has to be reliable and easily checked,
- it must be possible to identify the readings without error,
- a single manual capture of the data is all that is necessary, without adjustments at a later date,
- it must be possible for the operator to assess the credibility of the reading.

Instrumentation

The reliability of the installed instrumentation depends on factors related to the construction details. Generally, modifications to the system cannot be made when the dam is operational as many of the sensors are embedded in concrete. Periodic checks and redundant systems, such as those described in the document *"Measuring installations for dam monitoring"* [1] constitute the basic elements ensuring the reliability of the measurement chain.

Improving the quality of readings by easing the tasks of the operators

For a long time we have stressed the significance of the dam warden in security matters and the importance of their role. It falls therefore to the dam owner to create working conditions appropriate for the task in hand: each measuring point is a work place and it must be managed as such!

Furthermore, the dam warden must be given the means to avoid errors (be they fundamental or due to carelessness or distraction). The systematic use of digital measuring equipment reduces the errors in taking readings to a very low level.

The checks on the credibility of each reading on the basis of a representative model of reality is an essential element in the reliability of the measurement chain, because a dubious reading may be retaken *immediately,* without the delays which ensue through remote interpretations. The manual readings and the automated readings are complementary, they offer a first check.

With experience, the dam warden can immediately detect an abnormal value for certain parameters: those of the drainage water discharge, the concrete temperature, etc. However, this recognition is limited in scope and its reliability questionable. The dam warden will eventually compare a reading with an earlier value corresponding to a similar state of loading.

Having access to a numerical model allows an analysis to be made for the loading corresponding to that day, thereby providing a range within which the operator should find the measured value.

Easing the capture and processing of the readings

Each manual manipulation of data is a possible source of error. Taking a reading means it has to be transcribed at least once! But once is enough! With the entry of the readings into the computer at the measuring point, the value need not be recopied manually as it already exists in a state ready for the final processing.

6.4 Computerised solutions: an example of a practical application

The reliability of the surveillance process is immediately improved by the application of electronic-based systems starting at the taking of the measurements. In this example, the periodic inspection of the dam has been divided as follows:

At the control centre, before carrying out the readings:

- calculate the limit values for the readings for the particular day, on the basis of an appropriate analytical model,
- transfer these values to a portable "palm top" microcomputer.

At the dam, taking the readings (Figure 6.2):

- identify the reading point by a bar-code system,
- read manually, using appropriate equipment,
- enter the values into the palm top computer,
  - the plausibility check is carried out immediately, and
  - if the reading lies within an expected range, it is accepted, or
  - if a discrepancy appears, the operator can retake the reading or he can enforce the value,

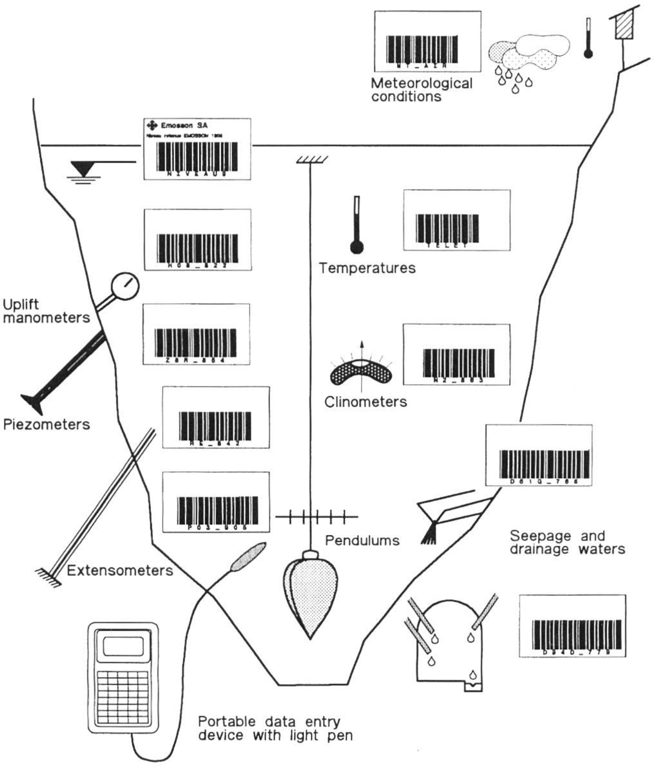


Figure 6.2. The identification by bar-codes and the capture by microcomputer making the measuring operations easier and more reliable.

- before leaving the dam the operator should reassure himself that all the readings have been carried out by using the appropriate functions on the palm top computer.

At the control centre, after the readings have been taken (Figure 6.3):

- the palm top values are transferred to the database of the microcomputer used for processing; they are added to the body of the existing data and to the readings taken automatically,
- these values are, simultaneously, electronically transmitted to the engineer,
- the operator can carry out the first analysis of the behaviour of the dam, according to the procedure established jointly with the engineer or dam expert.

The programme at the disposal of the operator for this analysis has to be the same as that used by the engineer; the version and modifications must be identical.

It must be able to provide an immediate visual presentation of:

- the last reading and the preceding readings across a minimum of a twelve-month period,
- the likely range of readings determined by the analytical model,
- and it must have the ability to review the behavioural history to compare the changes as a function of the different states of loading.

A visual-based programme such as this, linked to the database holding the values of several decades, allows the discovery of any remaining errors which could have an undesirable effect on the analytical model over a period of several years.

At the engineer's office

The analysis of the behaviour can be carried out with the minimum of delay, without intermediate manipulations which can be both tedious and risky.

6.5 Conditions for success

a) Materials

- In this application, the portable computers (a minimum of two, either hand held or palm top) have to be able to work in difficult environments. They have to be particularly resistant to shocks and high levels of humidity. Their reliability in functioning under such conditions should be well established. They have to be able to support a barcode reader (Appendix 1).
- Particular precautions should be taken when using barcode labels in these cold and damp conditions (Appendix 2).

b) Software

- Firstly, the analytical model which is used to predict the limit values has to be appropriate, with tight and realistic tolerances! If not, the objectives cannot be met.
- The database of a palm top computer has to be easily modified by the user enabling supplementary readings to be added or allowing adjustments to be made to the practical limits imposed on the values which cannot be predicted by the analytical model (for example, seepages influenced by rainfall or the melting of snow).
- The processing and manipulations must be simple, enjoyable and intuitive, so that the periodic use (typically, of the order of once a month) does not mean that the procedure has to be relearnt each time.
- In general terms, the dam warden must be able to choose his own sequence of taking measurements.

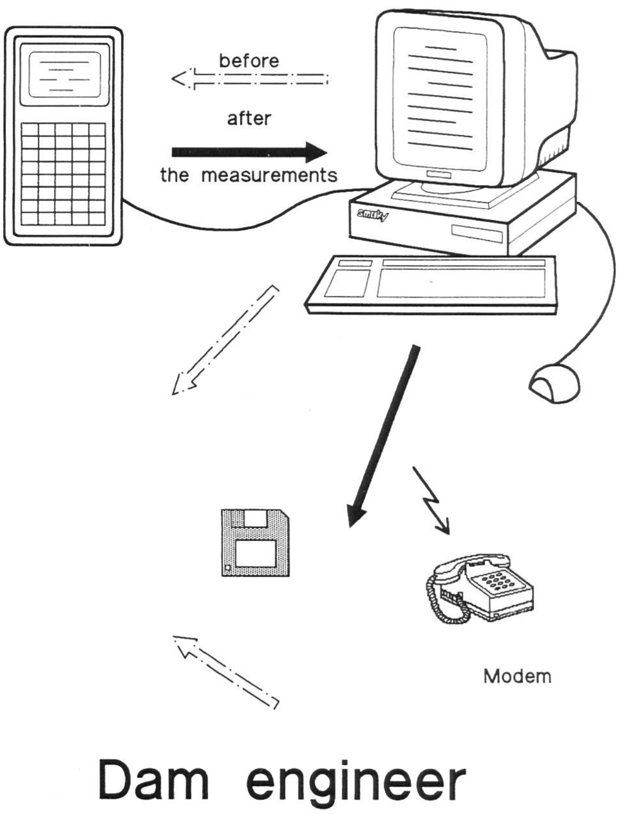


Figure 6.3. Following the capture and the credibility check on the readings, the data is transmitted by computer peripherals.

However, the palm top computer should remind him of the readings yet to be taken.

c) Human and psychological
- Particular attention must be paid to the involvement of the project manager and the dam wardens in the overall running of such a project. Firstly, the objectives to be achieved must be clearly explained and the ease with which the work can be carried out under the new system highlighted.
- Several psychological barriers remain to be conquered. The dam owner and the project manager must inspire confidence:
  - Adoption of a new technique necessitates careful preparation where stimulating interests is fundamental.
  - The rigour associated with the use of computers can surprise the dam wardens; the same rigour applies to those who take the readings!
  - The habit of using paper-pencil-rubber is hard to loose. The same thing applied when calculators were first introduced.

6.6 The working application

Following installation and a trial period, a list of benefits and inconveniences may be drawn up. This includes the following main points:

a) Key benefits
- The immediate check on the credibility of the recorded values guarantees the readings and reassures the dam operator.
- A value is transcribed only once, it is not processed manually later; hence an important source of error is eliminated.
- The immediate processing of the reading saves time and increases efficiency in the case of anomalies.
- The application of ever advancing technology motivates both the operators and those responsible for the dams.

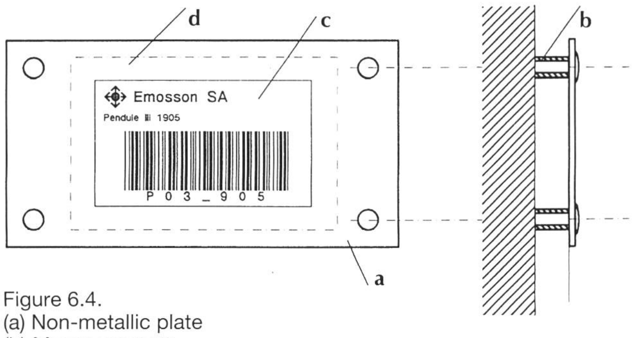


Figure 6.4.
(a) Non-metallic plate
(b) Mount support
(c) Bar-code label
(d) Plastic protection, border > 10 mm.

b) Factors which can be inconvenient
The dependence on both the staff and technology becomes greater. It is therefore necessary to pay particular attention to:
- the choice of material and the development of software,
- the working procedures, which must be carefully prepared, clear, precise and complete,
- training the operators, it is necessary to re-explain the roles that they play and underline their importance in the concept of dam security,
- their comments, biased towards practical aspects, to improve the ease of use of these tools.

6.7 Conclusion

The developments in microcomputing leads to a new application in the field of regular dam monitoring by improving the quality of the readings and the efficiency with which they can be processed.

The tasks of the dam wardens are more highly valued so that they generate greater interest in the system.

The trend towards lower computing costs yet higher computing power offers the possibility of incorporating such a system within a reasonable budget.

Figure 6.5. Automatic data gathering on a Palmtop pendulum in a dam inspection gallery.

Appendix 1: Use of microcomputers in data gathering

The equipment has to work in the field in difficult climatic environments. The following criteria controlling the choice of equipment are important:

Mechanical
- resistant to shocks, has to be able to withstand a drop-test,
- resistant to humidity and water; preferably sealed, including the connections,
- keyboard adapted to operators, with sufficiently large keys.

Electrical
- in the case of power surge, no loss of data,
- ability to work reliably in temperatures close to 0 °C,
- ability to operate with an independent power supply at low temperatures during transportation and usage,
- ability to connect a bar-code reader.

Software
- standard operating system supporting a current programming language and a conventional bar-code reader,
- standard interface connections.

Consider using protective covers both during transport and while working!

Appendix 2: Bar-code labels

The climatic conditions inside the dam mean that particular precautions need to be taken in placing the bar-code labels.

In order to avoid a premature deterioration of the labels due to humidities close to 100% and hence difficulties in reading, they must be adequately protected.

Concept and installation
Having determined the identification of a reading point and chosen the bar-code, for example CODE 39:

- Print the codes on standard paper labels with a high quality laser or ink-jet printer, with appropriate software. Keep one or two complete sets of labels in reserve.
- Stick them onto a non-metallic plate fastened away from the wall and cover the labels to guarantee their water-resistance.

It is also possible to use ready made labels produced by firms making flexible or rigid plastic mounts which can be attached directly.

7. Guaranteeing surveillance in exceptional circumstances

Exceptional circumstances may arise when:

- extreme water levels or technical breakdowns interfere with the functioning of the measuring equipment,
- the electricity supply breaks down,
- the transmission of information between the dam and the control centre is interrupted, or
- the dam wardens and/or engineers have to undergo military training during active periods of army service.

Even with these complications the surveillance of a dam and data checks can still be assured in a satisfactory manner.

An exceptional situation may be characterised by a breakdown in the automatic capture of data and/or their electronic processing which could be due to incomplete training of the replacement personnel. The optimum control of such situations demands that:

- the most important readings (and hence those most often automated) have to be taken regularly by hand and processed without electronic means. For these, the values have to be recorded monthly in a manner similar to that carried out during the inspections. The manual processing has to be undertaken once a year and has to be well documented;
- replacement personnel should be instructed and experienced in carrying out manual readings and trained to use the electronic equipment, as well as being taught how to implement the procedures for exceptional circumstances;
- the engineer responsible for the annual inspection must be informed of extraordinary circumstances arising. He must define the action to be taken by the appropriate replacement staff;
- preparations for alternative action in exceptional circumstances must be made. The use of a cumbersome system is to be avoided.

In any surveillance project, complete control during these exceptional circumstances must be maintained. In particular, the following must be addressed:

- provide easy access to important measuring points and have them prepared for manual readings which may be carried out with the minimum of delay,
- decide upon measuring points for reduced set of checks on the pendulums using the simplest deformation calculations,
- install instruments which indicate the values in the normal units,
- establish measuring formulae and data processing methods which lend themselves to highly readable diagrams incorporating appropriate instructions which are easy to use on site.

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