Instrumentation and structural monitoring of earth, rockfill and concrete dams

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Introduction

The design and construction of any structure requires consideration and assessment of the ability of the ground to support the construction. Since the designer of geotechnical construction deals with naturally occurring heterogeneous materials and does not know their exact engineering properties, he may only carry out tests in the laboratory and try to determine the engineering properties on the samples picked up from the field. But his structural design is essentially based on the values of engineering properties of the materials tested by him. Therefore, as construction progresses and exact geotechnical conditions observed or behaviour monitored by means of instrumentation, the design judgments may be evaluated and changes made, if necessary. The Paper presents Instrumentation as a tool to assist with these observations.

Instrumentation is used to measure the response (deformation, stress etc.) of soil or rock to changes in loading or support arrangements, and from the measurements taken, the need for modifications to the loading or support arrangements is determined and the construction is controlled. But instrumentation is also indispensable for site investigation, design verification, long term monitoring of the soundness of the structure and above all, its safety.

The author's Company has had long experience in having manufactured, installed and monitored instrumentation of various types of Dams in the world. The Paper highlights their experience in instrumenting different types of Dams such as concrete dams, earth fill dams, earth & rock fill dams, concrete face rock fill dams and roller compacted concrete dams.

Every type of Dam, and even every Dam of the same type, has its unique requirements of monitoring parameters and needs unique type of instrumentation. So the selection of instruments and their ranges has to be very focussed and must involve the user as much as the instrument manufacturer. The Paper presents the features and the salient aspects of different instrument available to the geotechnical and civil engineers to enable them to decide on the best of instruments to fit into their specific needs.

An aspect not easily appreciated is the proper installation of instruments. Unlike other industries, field instruments for getoechnical engineering are mostly embedded in soil or concrete and they are meant to become a part of the civil structure itself to continuously sense and feel the concerned geotechnical parameter of the structure. They are meant to provide this service throughout the lifetime of the structure. Once the instruments are embedded, they cannot be replaced. Under such stringent requirements, any instruments not carefully installed by experienced staff as per the manufacturer's Method Statements and User Manuals are likely to be a waste. The paper provides details of some typical installations of Dam instrumentation with site installation pictures illustrating practices followed for some instruments.

To summarise, geotechnical instruments are our eyes and ears inside the structure and provide valuable data for taking appropriate corrective actions before it is too late. The Author has presented data obtained from instrumentation from various types of structures highlighting the usefulness of instrumentation monitoring in the construction of dams.

1. Classification of Dams

Dams are at the heart of any scheme to harness the water resources and renewable hydrological source of energy. Depending upon their mechanism of load transfer to the foundations, dams may be classified as Gravity dams, Arch dams, Buttress dams etc. However, in this paper, since we are mainly concerned about instrumentation of the dams, we shall classify dams depending upon material of construction employed. With this consideration, dams may be classified into the following types:

1.1 Concrete Dam

The dam is generally of the gravity or the arch type, the name describing the means by which the dam maintains its stability. A gravity dam is designed with sufficient weight and base area to balance and resist the hydrostatic forces imposed by the reservoir, which tend to overturn the dam or slide it along the dam foundation. An arch dam is commonly built in a relatively narrow, steep sided valley where very competent and good quality rock is found in the side abutments and the foundation to take and withstand the thrust from the arching action of the dam.

1.2 Earth fill and Earth & Rock fill Dam

The earth fill dam uses earth on both the sides of the embankment to provide stability and an impervious membrane in the middle to provide water tightness. The membrane may be fine clay, a concrete slab, asphalt concrete paving or even steel plates. Earth & rock fill dam is similar in design and construction to the earth fill dam excepting that rock and earth is used in the embankment, instead of only using earth.

1.3 Concrete Faced Rock fill Dam (CFRD)

The construction of CFRD involves placing high-grade rock at the dam core and compacting them to their maximum strength. A reinforced concrete slab is constructed at the upstream face of the dam. The concrete face transfers the water pressure to the rocks and finally to the dam foundation. A reinforced concrete cut-off wall driven into the foundation on the upstream side helps to cut-off the foundation pore water pressure from the downstream of the dam.

1.4 Roller Compacted Concrete (RCC) Dam

In RCC dam mortar used is (cement + sand + fly ash + water + aggregates + admixture) and elevations are lifted in layers about 300 mm high. Roller is used to compact the material. The advantages are that the construction of the dam is much faster and is more economical especially where fly ash is available as a waste by-product from Thermal Power Plants.

This paper describes the author's experiences with the instrumentation of all the above types of dams.

2. Role of geotechnical instrumentation in design & construction of dams

The designer of geotechnical construction works with naturally occurring materials, and does not know their exact engineering properties. He may carry out tests in the laboratory on the samples picked up from the field, and sometimes change the naturally occurring materials to make them more suitable for his needs. But his structural design will essentially be based on the values of engineering properties of the materials tested by him. Therefore, as construction progresses and exact geotechnical conditions observed or behaviour monitored by means of instrumentation, the design judgments are evaluated and changes made, if necessary. Hence observations by means of monitoring instruments during geotechnical construction are an integral part of the design process. Instrumentation is a tool to assist with these observations.

Post construction, the instruments are used for assessing soundness of the constructed Dam. They are used to measure seepage of water within and below the dam, important parameters within the dam structure, and the stability of the dam as whole with regard to its surroundings.

2.1 Purpose of instrumentation

Broadly, a good instrumentation program may have one or more of the following purposes in mind:

- Site investigation
- Performance monitoring
- Construction control

- Design verification
- Safety
- Legal protection

Instruments provide designers and contractors the basis of a legal defence should resident and owners of adjacent properties blame construction for damage to their property and life. This aspect gains prominence in constructions in populated areas such as for underground metro railways.

2.2 Measurements from instrumentation

A good instrumentation program should cater to the following measurements:

2.21 During construction/excavation

- To verify the hypothesis and the assumptions of design.
- To monitor safety during construction.
- To measure change in parameters during construction.
- To ensure that interface of construction with adjacent structures and foundation is sound.

2.22 After construction is completed

- Performance monitoring for safety during the life of the structure.
- Evaluation of effect of operation of reservoir on parameters like stress, strain, water pressure, inclination, deflection and water seepage etc.
- Monitoring of reservoir level and water discharge.
- Making all monitored data and alarms available on the internet all the time

2.23 For research purposes

- Determination and evaluation of design parameters.
- Testing of new construction materials and techniques.
- Study of the laws of behaviour of soil, rock and man made materials used in the construction of such structures.

3. Choice of instrumentation

The choice of instrumentation differs from construction to construction. It depends upon the height and length of the dam, width of the blocks, state and nature of the foundation and faults in it, water level in the reservoir and several other factors, which the designer wants to be monitored and evaluated. The type and the number of instruments to be installed depend upon their necessity. A good instrumentation program is the result of collaborative efforts of the user and the instrument supplier. Much depends upon what the user and his designer want by way of optimum instrumentation and how they define their requirements to the instrument manufacturer.

Unlike any other types of instrumentation, the instrumentation for geotechnical applications is not predefined for a given type of structure. It is different for different structure, and may also be different for every structure of the same type.

From the experience the author has in this field, the type and usefulness of the instruments for different types of dams can be conveniently studied by classifying the study into the following broad categories:

- Instruments to monitor parameters related to seepage of water
- Instruments to monitor other parameters within the dam structure
- Instruments to monitor dam structure as a whole with respect to its surroundings
- Installation & Monitoring aspects

The following is a study of the instrumentation of different types of dams:

4. Instrumentation of a concrete dam

4.1 Instruments to monitor pore water pressure and seepage of water

4.1.1 Uplift pressure meter

The uplift water pressure is due to water seepage from the reservoir to the foundation of the dam. This pressure exerts a vertical upward force on the base of the dam and tries to lift it up. Uplift pressure is monitored by uplift pressure meters, which are mounted on the top of the uplift pressure pipes. In case the uplift pressure reaches a certain high limit, a stop valve on the uplift pressure pipes is opened to release the water and reduce the pressure on the base of the dam.

4.1.2 Pore pressure meter

The pore pressure meter is the single most important measuring instrument used in dams. The pressure of water within pores of concrete (or soil or rock) results in the seepage of water through the cross-section of the dam. A pore pressure meter is generally also mounted next to a stress meter for deducting the pore pressure and for arriving at the true stress at that point.

4.1.3 Seepage measuring device

While the pore pressure meters described above provide an indication of the extent of seepage, the amount of actual seepage taking place in a dam must be measured to determine the dam safety and the deterioration of the dam structure with time. Drain outlets are commonly used at the downstream side of the dam to collect the seepage water and measure its flow rate.

4.2 Instruments to monitor other parameters within the dam structure

4.2.1 Stress meter to monitor stresses

Stress meters are located in zones subjected to compression. The maximum stress develops near the foundation and at locations where the height of the dam is maximum. As the dam fills up with water, this stress in the foundation shifts from the upstream side to the downstream side. The stress meters should therefore be located in these maximum stress locations.

4.2.2 Strain meter to monitor strains

Normally, the strain meters are embedded in a group of five to measure the strains in the vertical, cross horizontal and transverse horizontal directions. In some applications where reliable data is of extreme importance, project designers use a set of thirteen strain meters in desired locations.

The strain meter cannot determine whether the deformation is due to stress, change in temperature or autogenous growth. In all locations where group of strain meters are embedded, it is normal practice to embed an additional strain meter in a no-stress container. By deducting the reading of the strain meter mounted inside the no stress container individually from the readings of strain meters mounted in the groups, change in strain due to stresses in the dam is monitored.

4.2.3 Temperature meter to monitor temperature gradients

Measurement of temperature plays a very important role in the construction of a concrete dam. Due to heat of hydration, if temperature of the concrete rises above permissible limit, undesirable micro-cracks would form in the concrete. Temperature probes are therefore mounted at various places for the measurement and monitoring of temperature during the casting of the concrete. Even post construction, temperature variation is one of the major factors causing stress on the surface of the dam. This is particularly so in the spillway areas where water effects the temperature on the surface and sun and snow result in excessive temperature gradients. Stress developed due to these temperature changes is cyclic in nature and results in material fatigue.

4.2.4 Joint meter to monitor relative displacement of adjacent blocks

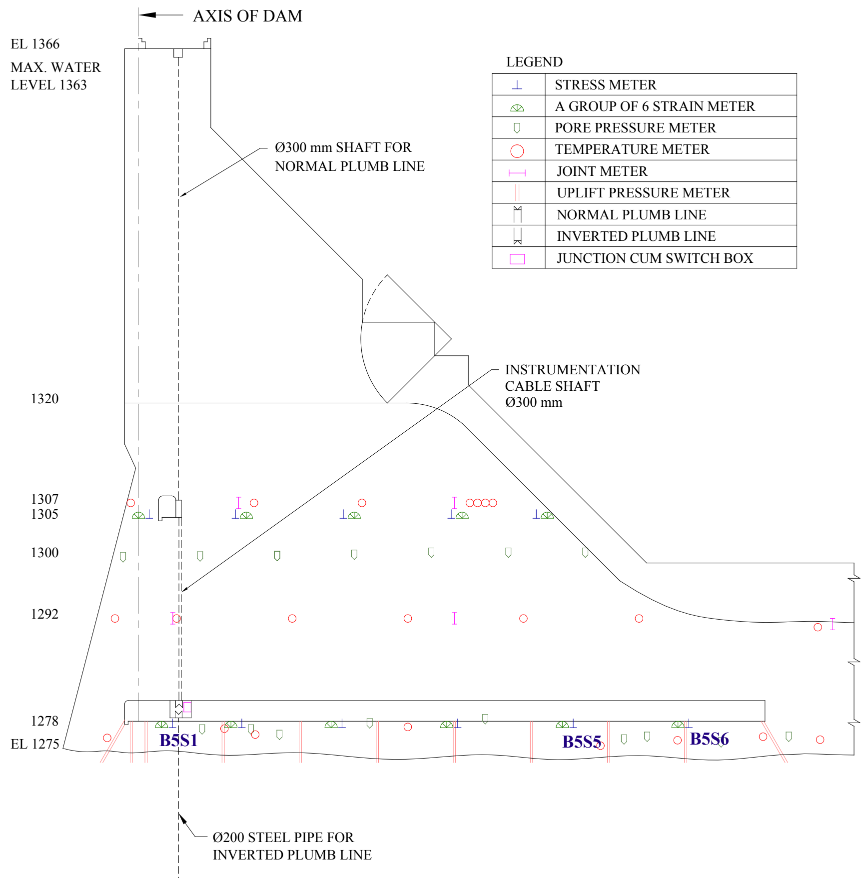
Concrete dams are built in blocks, as it is not possible to pour concrete at any level along the complete length and width of the dam. This results in joints between concrete blocks. From the point of view of monitoring water seepage through dams and taking corrective action, it is necessary to measure joint openings. The joint meters can be uniaxial, measuring displacement in a direction parallel to the dam axis (x direction); or they can be biaxial or triaxial measuring displacements in y and z directions as well. Biaxial and triaxial joint meters can be mounted inside the structure or in the gallery.

4.3 Instruments to monitor dam structure as a whole with respect to its surroundings

4.3.1 Normal Plumb Line to monitor tilt of the dam with respect to its base in x and y directions

Change in water level changes the thrust on the dam due to water pressure and results in the movement of the dam top in respect to the base. Plumb line is used in one or more blocks to measure and monitor the tilt of the dam.

Fig1: Instrumentation of spillway block of a concrete dam



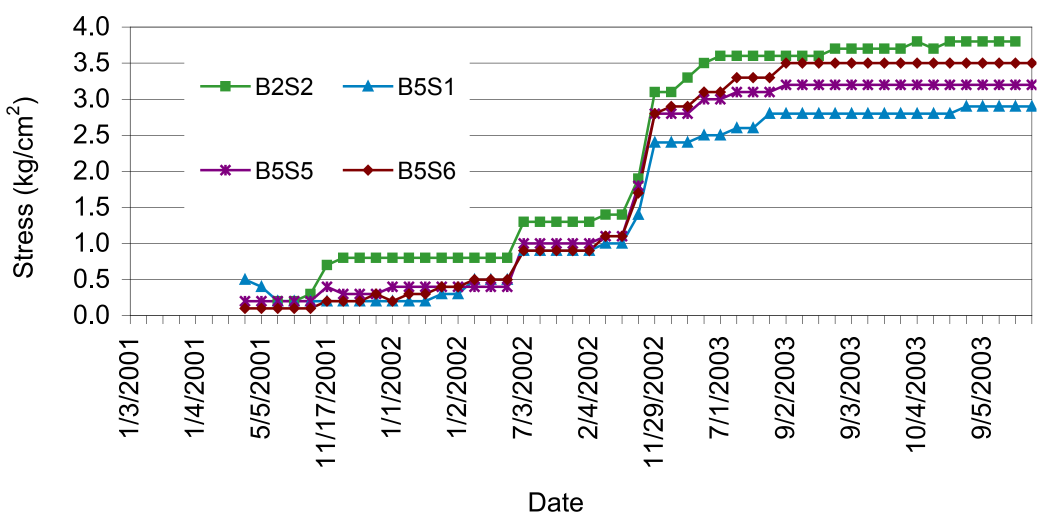


Fig 2: Stress measurements during construction (See figure 1 for locations of B5S1, B5S5 & B5S6)

4.3.2 Inverted Plumb Line to monitor horizontal displacement between dam bottom and foundation base rock in x and y directions

It is also necessary to measure the relative displacement between the dam bottom and the foundation base rock. An inverted plumb line is used for this purpose.

The plumb lines, if installed correctly, are very reliable instruments of measurements. Optical readings taken mechanically during maximum and minimum water levels are usually sufficient for monitoring the dam. However, by adding an electronic measurement system, the displacements can be monitored remotely in the dam top observation room.

4.3.3 Bore hole extensometer to monitor vertical displacement between dam bottom and foundation base rock in z direction

For measurement of the vertical displacement of the dam bottom in respect to the foundation base rock, a borehole extensometer is used. See figures 3.1 & 3.2.

The measurement should be taken at all locations where foundation deformation is expected to take place.

4.3.4 Bore hole extensometer to monitor displacement between dam and the abutment

Displacement of the dam body with respect to the abutment is also monitored by means of single or multi point bore hole extensometers.

4.3.5 Water Level Measurements

Electronic vibrating wire type, strain gage type or radar type level transmitters may be used for remote indication of water level.

4.4 Installation of instruments

The necessity of good quality instruments for the largely embedded geotechnical applications is perhaps quite well understood. However, what is not easily understood and often underestimated is the necessity of good quality installation. An embedded instrument has to become a part of the geotechnical structure and sense the parameter with it. If it is not able to sense the desired parameter, the instrument is of no use to the geotechnical engineer, howsoever-good quality it might be. In fact in geotechnical instrumentation, the quality of installation is as important as the quality of manufacture and must share equal weightage. There have been number of incidences in the past where good quality instruments have failed to perform because of poor installation practices.

From the author's experience, a few points to remember for good quality installation are as follows:

- For proper installation, the documents like User's Manual and Method Statements provided by the manufacturer must be strictly followed. Also, only personnel having long and proven experience in this field must perform the installation.
- Location of every instrument, the routing of its cables and the location from where the instrument is to be monitored during and after construction must be planned well in advance. This will ensure that the civil contractor follows the drawings meticulously. It must be realised that the civil construction work generally extends over a number of years and the instruments and their cables have to be protected throughout these long years of construction. The instruments must also be continuously monitored althrough the construction work as this data during the construction period is invaluable for the geotechnical engineer to take appropriate decisions during construction.
- Installation of plumb line, drilling of a vertical shaft for the inverted plumb line, fixing of the wire of the normal plumb line to the dam top, providing proper recess at the proper place in the gallery to mount the tank and table for the plumb line are all activities that need very special care.
- All instrument cables must be well protected and the sensor connected to each cable pair must be identified all through the construction work.

Fig 3.1: An array of extensometers for dam base settlement monitoring

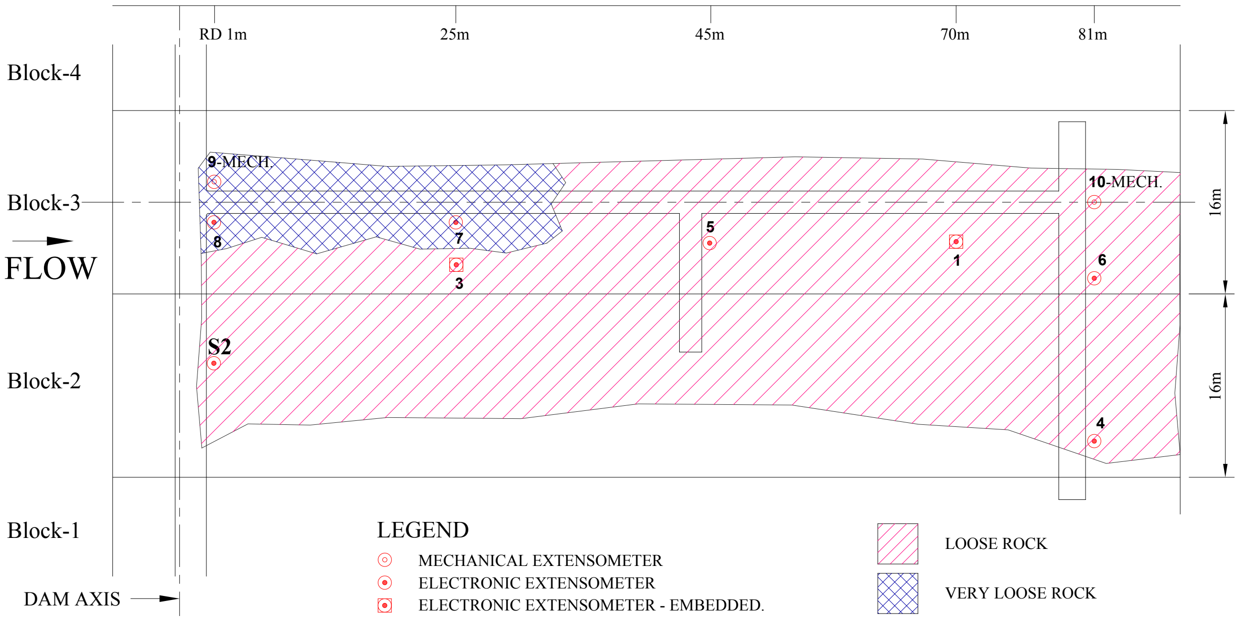
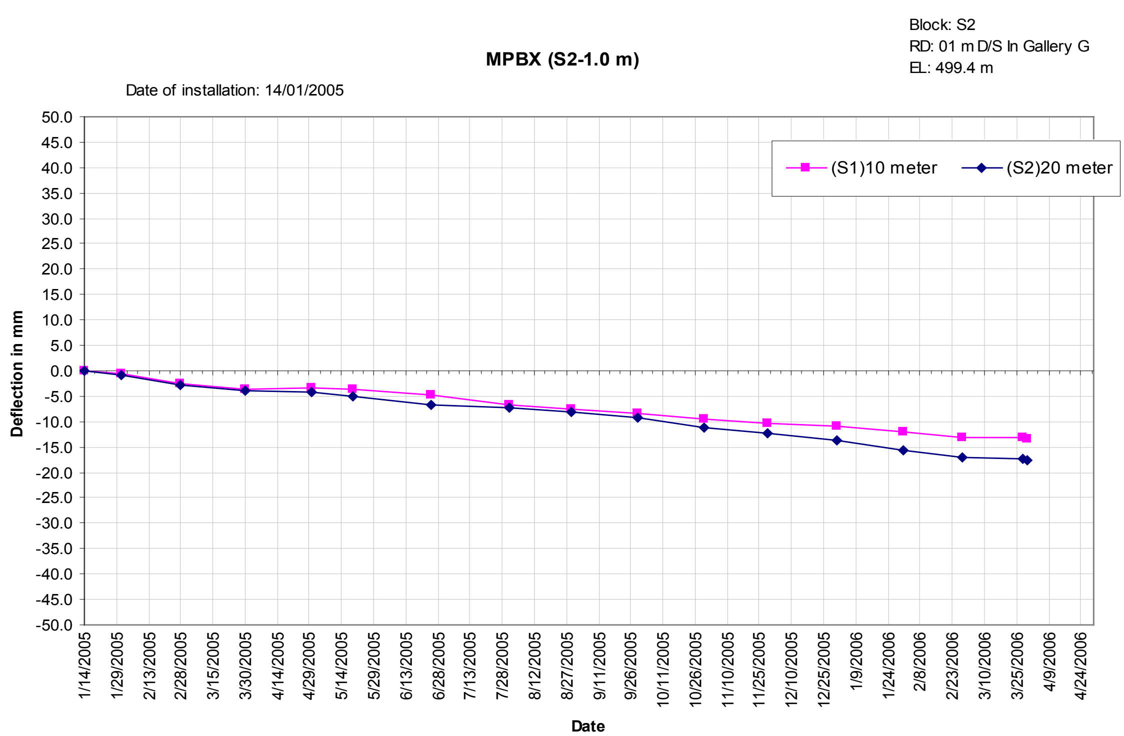


Fig 3.2: Dam base settlement monitored by a 2-pt extensometer



- Exposed cables must be carefully protected from damage and all surface mounted instruments must be regularly maintained.
- Where an automatic Data Acquisition System (DAS) is installed, instrument cables must be adequately separated from power cables. Otherwise the DAS shall also pick up electromagnetic noise and the data given by it shall not be faithful.

4.5 Monitoring of data

During construction phase, data from the instruments is monitored manually by means of portable data loggers. Post construction, the data is monitored automatically by Data Acquisition System with web based monitoring such that the instrument data is available on the Internet to authorised users.

From the author's experience, a few points to remember for monitoring are given below:

- The initial readings and other constants of all the parameters monitored must be carefully preserved throughout the period of construction of the dam. If this invaluable information is lost, the very purpose of the instruments is likely to be lost.
- The identification of all instruments must be carefully preserved. There have been cases where cable tags have been lost or washed away in floods with the result that no one knows the location of the various sensors within the structure where the data is coming from.

5. Instrumentation scheme for earth or earth & rock fill dam

5.1 Instruments to monitor pore water pressure and seepage of water

5.1.1 Foundation piezometers

The instruments are foundation piezometer, pore pressure meter and seepage measurement device, which are generally the same as in the case of concrete dam described before.

5.2 Instruments to monitor other parameters within the dam structure

5.2.1 Soil stress meter

Soil stress meters are used in an earth or earth & rock fill dam in a similar way as they are used in a concrete dam. However, there is a difference in their construction as soil stress meters do not have a pinch tube unlike stress meter for concrete.

5.2.2 Inclinometer and magnetic settlement system to measure small movements in x, y and z directions

To measure lateral (x,y) movements of embankments and foundations, an inclinometer system is used. If the displacements in a vertical direction (z axis) are to be monitored, a magnetic settlement device is used. To investigate the movement in x, y and z directions, an inclinometer system with magnetic settlement device is used.

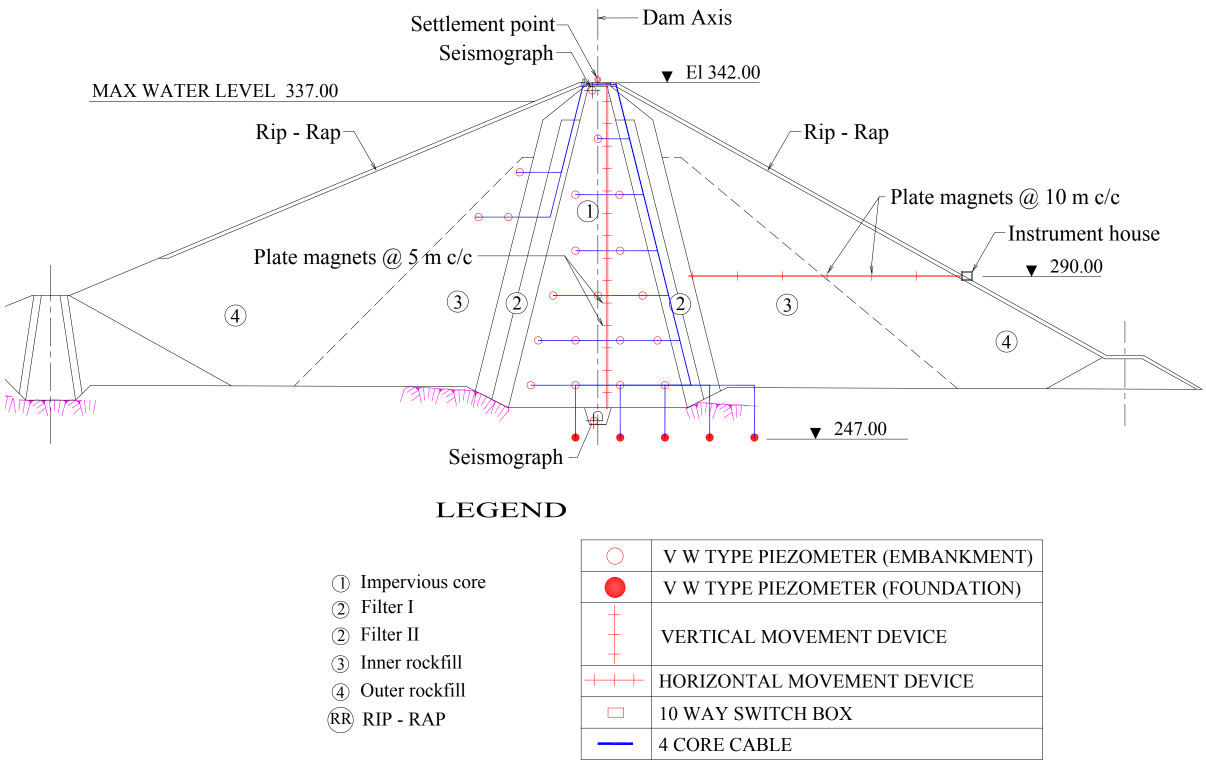
5.2.3 Magnetic or electronic vibrating wire extensometer system to measure horizontal displacement

To measure larger movements of embankments in horizontal direction, a horizontal magnetic displacement measurement device, similar to the magnetic settlement device mentioned above, is installed in the horizontal direction. See figures 5 & 6.

If it is required to measure horizontal displacement of the upstream dam embankment where no monitoring room can be constructed, a series of electronic vibrating wire type extensometers are laid in a horizontal array. The cables from all sensors are carefully routed up to top of the dam in the monitoring room to observe data.

5.2.4 Hydrostatic settlement system or vibrating wire settlement cell system to measure vertical displacement

In an earth or earth & rock fill dam, measurement of settlement of the embankment as dam height is raised, is of utmost importance. Several methods are available for the measurement of this important parameter. For settlement measurements in downstream embankment, the hydrostatic settlement system is used with its monitoring station built on the downstream embankment. However, where settlement is required to be monitored on the upstream side, *Fig 4: Typical Instrumentation scheme of an earth and rock fill dam*



the vibrating wire settlement cell system is used with the monitoring station at the abutment or on top of the dam.

5.3 Instruments to monitor dam structure as a whole with respect to its surroundings

Water level measurements and installation/monitoring practices for instrumentation

These aspects are similar to those in concrete dams described before.

6. Instrumentation scheme for a Concrete Faced Rock-filled Dam (CFRD)

Owing to the construction of the CFRD, its key instrumentation involves measurement of deflection of the concrete slab, joint openings between the various blocks of the slab as well as between the slab base and the plinth and the joints between the plinth slabs.

The instrumentation of a CFRD, where author was involved, was done in the following manner:

6.1 Instruments to monitor pore water pressure and seepage of water

6.1.1 Foundation piezometers

Electronic vibrating wire type pore pressure meters (PPG) were installed before and after the cut off wall to assess the effectiveness of cut off wall. The instrument cables were routed to the dam top control room for monitoring.

Fig 5: Horizontal Magnetic Extensometer System

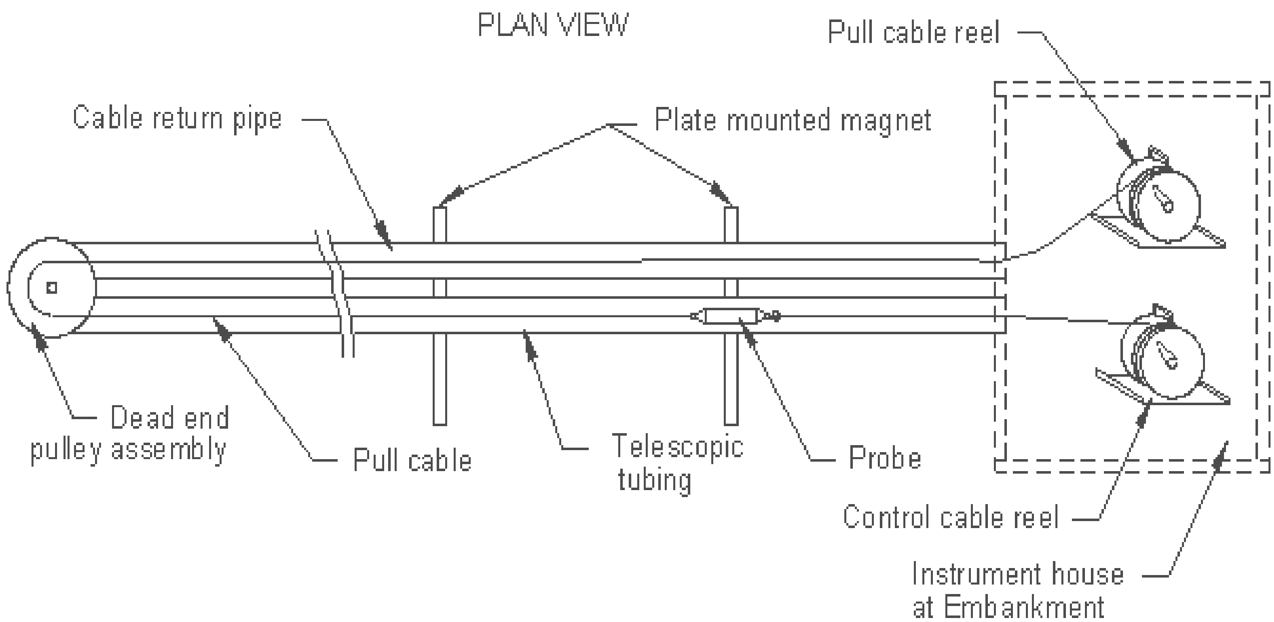


Fig 6: Installation of Horizontal Magnetic Extensometer System

Fig 7: Instrumentsof a typical section of Concrete Faced Rock-filled Dam

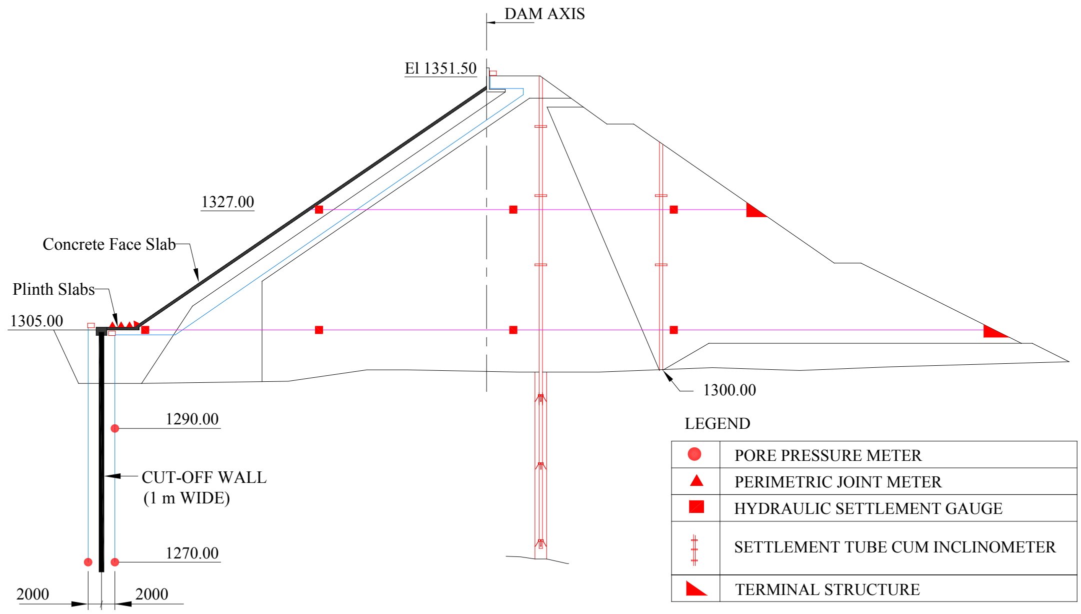


Fig 8: Monitoring of deflection of concrete face slab by Electro levels

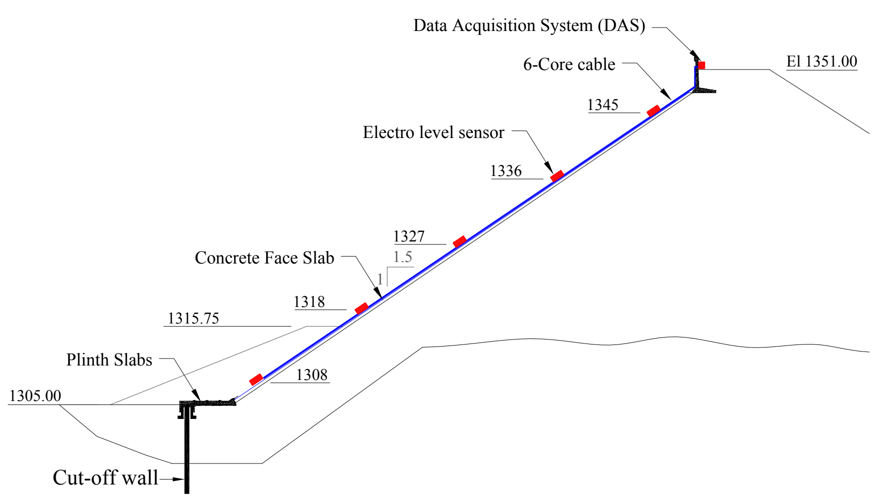
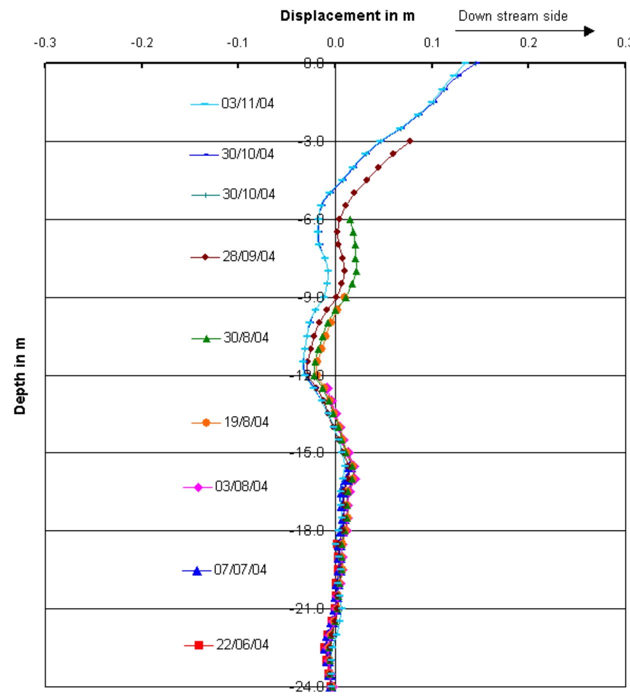


Fig 9: Displacements during construction as monitored by inclinometer



6.2 Instruments to monitor other parameters within the dam structure

6.2.1 Inclinometer and Electro level system to measure displacement of the concrete face

The inclined inclinometer system was used for this purpose. The ABS tubing of the inclinometer system was laid inside MS pipe of dia 150 mm, welded in the reinforcement cage of the slab prior to casting of concrete. The annular space between ABS tubing and the MS pipe was filled with grout. Observation of the probe was taken in two mutually perpendicular directions and deflection of the ABS tubing plotted with respect to the distance from the bottom.

Electrolytic level sensors were used at intervals of 9-10 m along the section of the slab as shown in Figure 8. The tilt of each sensor was measured and thus displacement of the slab at the points where the sensors were fitted was determined in two mutually perpendicular directions. On this basis, the current profiles of the section of the slab were drawn and compared with the earlier ones.

6.2.2 Inclinometer and magnetic settlement system to measure small movements in x, y and z directions

This measurement is the same as for earth and earth & rock fill dams described under section 5.2.2. Figure 7 shows the location of settlement tubes and figure 9 shows the displacement of the tube during installation. This reading is taken as the base reading and all subsequent movements are measured with respect to this base reading (y-axis).

6.2.3 Hydrostatic settlement system (HSG) or vibrating wire settlement cell system to measure vertical displacement

This measurement is the same as for earth and earth & rock fill dams. Please refer to section 5.2.4.

Some of the instruments located in a section of CFRD are shown in Figure 7.

6.2.4 Triaxial or perimetric joint meters (PJM) to measure movements between various blocks of the plinth slabs

The plinth slabs are subjected to heavy hydrostatic pressure and may undergo displacements in x, y or z directions.

Therefore, water proof triaxial joint meters were installed between the adjacent plinth slab blocks with their cable brought up to the dam top control room in conduits laid below the concrete face slab.

6.2.5 Linear joint meters to measure movements between various concrete face slab and plinth slabs and between various block of the concrete face slab

Since these structures are subjected to heavy hydrostatic pressure, their relative displacements were monitored.

6.3 Instruments to monitor dam structure as a whole with respect to its surroundings

Water level measurements and installation/monitoring practices for instrumentation

These aspects were similar to those in concrete dams described before.

7. Instrumentation scheme for roller compacted concrete (RCC) dam

Cast Concrete Dams & Roller Compacted Concrete (RCC) Dams

The main difference between a concrete dam and a roller compacted concrete dam is that in a concrete dam mortar (cement + sand + water + aggregates) are used and elevations are lifted in sections about 2 m high. In RCC dam mortar used is (cement + sand + fly ash + water + aggregates + admixture) and elevations are lifted in layers about 300 mm high. Roller is used to compact the material. The exothermic reaction causes temperature of concrete to rise and it reaches a peak in a few days. The cooling process takes several months or years until a steady state is reached. Thermal cracking is therefore a major risk in RCC dams.

The author has used the following types of instruments in an RCC dam:

7.1 Instrumentation of test section

To decide the ideal composition of mortar and fly ash, a test section of about 500 m length, 1 m height & 10 m width was created. During the test the moisture, relative humidity and temperature of the concrete were checked.

Geotechnical instruments employed in RCC dams are generally of the same type as in any cast concrete dam but few important differences were as follows:

- Temperature monitoring of concrete assumed critical importance. A system was therefore deployed to monitor the temperature rise and cooling in the dam body due to the heat generated by the exothermic reaction of cement with water. The temperature of the concrete was regularly monitored every six hours right from the time of dumping of concrete till after completion of the dam, until the temperature at various points achieves a steady state.
- Utmost care was taken during installation and special techniques adopted to protect embedded instruments from possible damages during roller compaction processes.

7.2 Instruments to monitor pore water pressure and seepage of water

Foundation piezometers, pore pressure meters and seepage measuring devices were used in the same manner as in the case of a concrete dam. See sections 4.1.1, 4.1.2 & 4.1.3.

Various types of instruments located in a section of RCC dam are shown in Figure 10.

7.2 Instruments to monitor other parameters within the dam structure

7.2.1 Concrete stress meter

Similar to those used in a concrete dam-please refer to section 4.2.1. However, the installation of stress meter in a RCC dam required special care to prevent damage of the installed instrument by the movement of rollers on concrete.
The stress meter was first installed in a block of concrete. The pinching process was completed and the concrete block allowed curing for seven days. Thereafter the concrete block with stress meter inside was shifted to its proper location before roller compacting of the dam concrete.

7.2.2 Concrete strain meter

Similar to those used in a concrete dam-please refer to section 4.2.2. Strain meters were installed in the concrete placed in a formwork located at the same place in the dam where the strain meters were to be placed. The strain meters were installed and concreted in the formwork. After curing, the formwork was removed leaving just the concrete block with strain gages embedded in it. RCC dam concrete was then be laid over the concrete block and rolled over by rollers without causing any damage to the instruments.

Fig10: Instrumentation section of a Roller Compacted Concrete (RCC) Dam

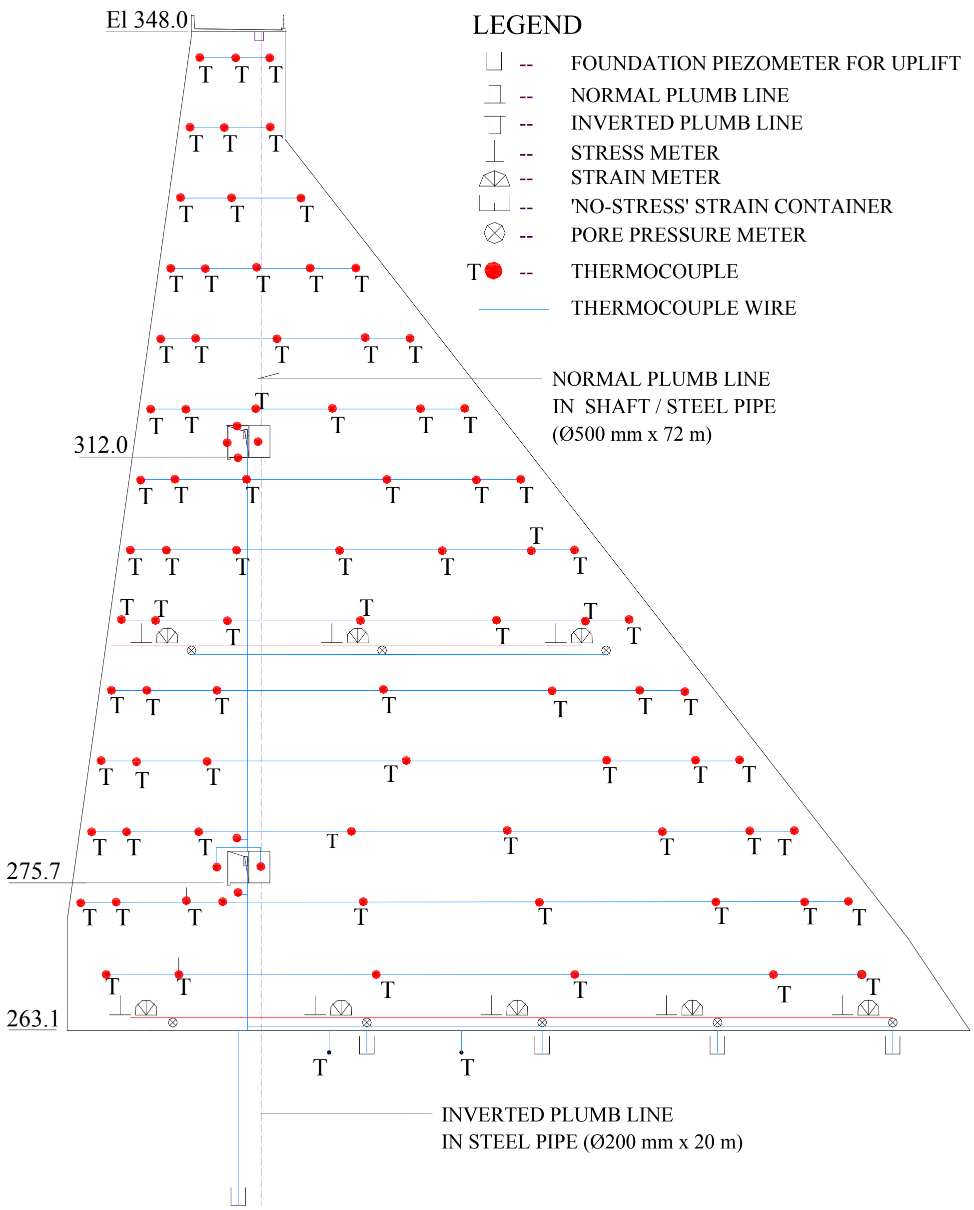


Fig11: Installation of stress meters in a concrete block to be later shifted to its location in RCC dam

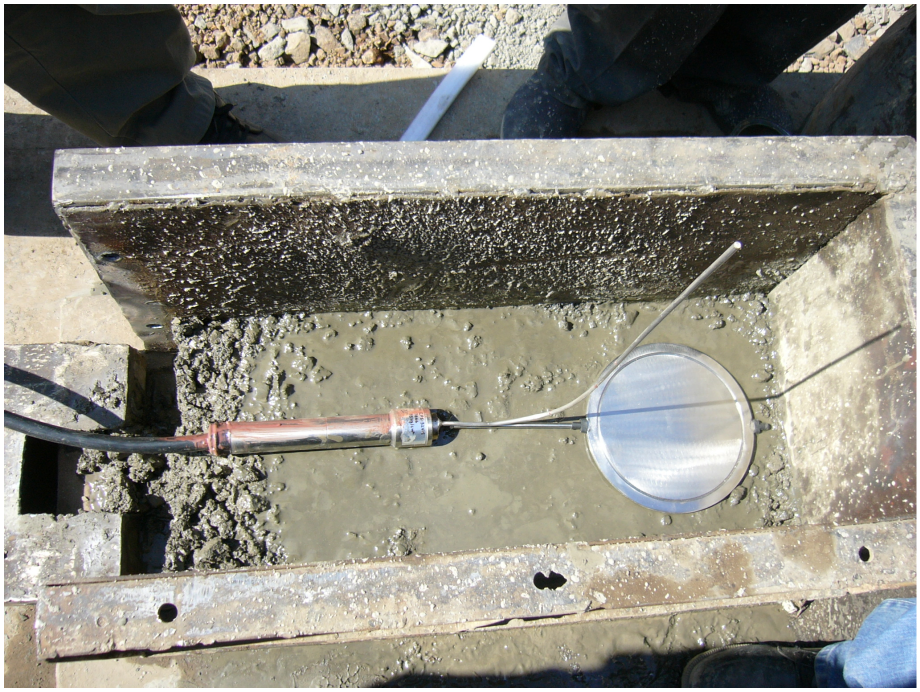


Fig 12: Formwork for installation of strain meter group at RCC dam site. The stress meter cast in a concrete block and the no-stress-strain container can also be seen.

7.2.3 Thermocouples for temperature measurement

Measurement of temperature is by far the most critical measurement and plays a very important role in the construction of a RCC dam. If temperature of the concrete rises abnormally due to heat of hydration, undesirable micro-cracks would form in the concrete. Numerous probes were mounted at various places for the measurement and monitoring of temperature. Figure 10 shows a distribution of temperature probes mounted all over the RCC dam. A combination of vibrating wire temperature meters and copper constantan thermocouples was used. All temperature probes were monitored every six hours throughout the construction of the dam by means of a portable read out unit. In case of an abnormal increase in temperature, the speed of construction had to be slowed down to maintain the temperature within limits.

7.2.4 Tri-axial joint meter

Vibrating wire type tri-axial joint meters were installed at regular intervals in the joints formed by inducer plates in the roller compacted dam portion as well as in the joints of spillway portion to monitor displacements in three mutually perpendicular directions.

7.3 Instruments to monitor dam structure as a whole with respect to its surroundings

Water level measurements and installation/monitoring practices for instrumentation

These aspects were similar to those in concrete dams described before.

8. Performance of instruments

With the special care taken to embed the instruments and protect the cables, all instruments installed will perform normally. In author's personal experience, it has been possible to achieve a 95-100 % success rate on the performance of instrumentation.

9. Conclusion

The use of instrumentation is an essential part of any construction activity today. Geotechnical instrumentation is different from any other type of instruments in that it needs a comprehensive and complete interaction between the designer, the user and the instrument supplier. Proper installation of geotechnical instruments is as important as the quality of instrument itself since once embedded, the instrument cannot be taken out. If an instrument has failed after installation, it cannot be replaced. No benefit can be obtained from these instruments unless the instruments are installed properly, the data monitored regularly and made available to the user readily for example over the Internet. And last but not the least, the data must be interpreted and made use of by the user at all times.

The Author

V K Rastogi (born 1947) took his Electrical Engineering (Hons) Degree from the University of Rajasthan, India in the year 1970. During his long and distinguished career in the filed of instrumentation, he has worked on instrumentation system design of power plants, process industries and civil structures. In 1982, he founded the Control Systems Division in UPTRON with American collaboration. From 1993 onwards, he is working with Encardio-rite Electronics Pvt Ltd, Lucknow, India and is presently a Director in this company, heading its Marketing Division. For the past 16 years he has been associated with the instrumentation of numerous civil construction projects that included almost all Dams and Hydro-electric Projects that were built in India during this period.