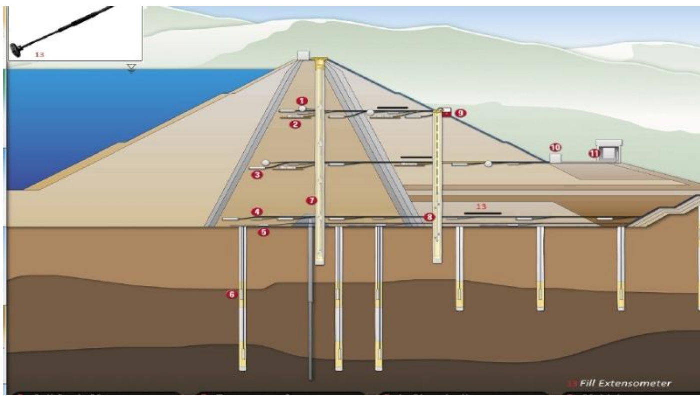
TECHNICAL MANUAL
ON
INSTRUMENTATION OF DAMS



CENTRAL WATER COMMISSION
MINISTRY OF JAL SHAKTI,
DEPARTMENT OF WATER RESOURCES,
RIVER DEVELOPMENT & GANGA REGUVENETION

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Government of India
Central Water Commission
Central Dam Safety Organisation

Technical Manual
on
Instrumentation of Dams

December, 2022

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Disclaimer

The Central Water Commission cannot be held responsible for the efficacy of the Instrumentation developed based on this Manual. Appropriate discretion may be exercised while preparing and implementing an instrumentation program.

Chairman
Central Water Commission
Department of Water Resources, RD & GR
Ministry of Jal Shakti

MESSAGE

India ranks third globally in the number of large dams, 80% of which are more than 25 years old. The health and safety of dams are of paramount importance for their long term sustainability. Central Water Commission (CWC) has for over last four decades been proactively promoting dam safety practices in the country. The Dam Safety Act, 2021 *inter alia* provides for surveillance, inspection, operation and maintenance of the dam for prevention of dam failure related disasters.

The importance of instrumentation for a good dam safety program is accepted world over. Instrumentation plays a fundamental role in understanding the foundation and structural behavior, both, during construction as well as operation of the dams. Dam Instrumentation and monitoring, combined with vigilant visual observations, can provide early warning and inputs for many conditions, which if unattended, can eventually lead to dam incidents and failures.

Instrumentation and monitoring need to be carefully planned and executed to meet defined objectives. There are no simple rules or standards for determining the proper level of instrumentation and monitoring for dams. The extent and nature of the instrumentation depends not only on the complexity of the dam and the size of the reservoir but also on the potential for loss of life and property downstream. Continued monitoring is essential to make sure that the selected remedy remains effective. Involvement of qualified personnel in the design, installation, monitoring and evaluation of an instrumentation system is a pre-requisite to the success of the program.

The Manual on "Instrumentation of Dams" has been compiled by Central Water Commission covering various aspects of instrumentation of Concrete and Embankment dams. I hope this Manual will be found useful by Water Resource Engineers and other stakeholders in finalization of dam instrumentation programme to evaluate performance of the dam so as to take timely corrective measures and ensure safety and longevity of the dam.

28.12.2022
(J. Chandrashekhar Iyer)
Chairman

New Delhi
December, 2022

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Member (Design & Research)
Central Water Commission
Department of Water Resources, RD & GR
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FOREWORD

The Design and Research Wing of Central Water Commission, provides consultancy and guidance to all the State Water Resources and Irrigation Departments, with respect to planning and design of water resource projects. Consultation and design of instrumentation for Dams and other structures is one of the important areas of work.

The most important objective of dam instrumentation is to provide structural behavior information to compliment an adequate dam safety inspection and surveillance programme. Study of structural behaviour through instrumentation also facilitates calibration and validation of numerical studies with prototype behavior.

The number of instruments, their exact type or location, is primarily a matter of experienced judgement. The minimum recommended instrumentation is limited to that which clearly provides useful information for evaluating dam safety. Every instrument installed on a dam must be carefully selected, located and installed. The instrument data must be properly collected, tabulated, plotted and judiciously evaluated in a time bound manner to achieve the intended purpose.

A need was felt for preparation of a technical manual based on the Indian Standard Codes and CWC Guidelines for reference and to be used by Dam owners/Project authorities. Accordingly, the current Manual has been compiled, covering various aspects of Instrumentation in Concrete and Embankment dams by Central Water Commission on the basis of available IS codes, CWC Guidelines & specifications and other relevant national/ international publications. An attempt has been made to include the provisions contained therein to make the Manual exhaustive covering all aspects of instrumentation; however suggestions for its improvement are welcome.

I hope this Manual will help the dam owners and practicing engineers in planning, monitoring, evaluation and long-term health assessment of dams. I complement the officers and staff of Instrumentation Directorate, Dam Safety Organisation, CWC for their efforts in compilation of this Manual.

नवीन कुमार
28/12/2022

New Delhi
December, 2022

(Navin Kumar)
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Chief Engineer
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PREFACE

The primary purpose of instrumentation is to supply data to aid in evaluating the safety of a structure by collecting quantitative data on its performance and by detecting problems at an early and preventable stage. Effective instrumentation can play a vital role in the ongoing assessment of a dam's performance, can provide valuable information concerning the safety of the dam and can help to improve dam design in the future. Appropriate instrumentation is the prime requisite for monitoring the behaviour of a dam both during construction as well as operational life.

The instrumentation alone is not a complete safeguard. The number of devices installed is less important than the selection of proper type of instruments, their location at critical points and intelligent interpretation of data. The extent and nature of the instrumentation depends not only on the complexity of the dam and the size of the reservoir but also on the potential for loss of life and property downstream.

Technical Manual on "Instrumentation of dams" has been prepared by Central Water Commission for reference and to be used by Dam owners/Project authorities and all those associated with dam instrumentation. The Manual covers Instrumentation Planning for Concrete and Embankment dams including Parameters to be monitored, Types of Instruments, Typical Specifications of Instruments, Installation of Instruments, Instrumentation Data Collection, Processing, Analysis and Presentation, Archival and maintenance of data. The draft manual was also forwarded to the apex organizations in the field of instrumentations i.e. CSMRS, CWPRS and NIRM for their valuable suggestions/review for finalization of the manual. Accordingly, the valuable suggestions/observations received from these organizations have suitably been incorporated.

Though effort has been made to make the Manual exhaustive; but it may not be complete in itself. Any suggestion for improvement of the manual is welcome. The Manual will help the dam owners and practicing engineers in monitoring, evaluation and long-term health assessment of dams.

(Vijai Saran)
Chief Engineer (DSO)

New Delhi
December, 2022

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SCOPE:

A large number of river valley projects have been taken up / contemplated in the past few years, with a view to cater to our growing hydropower and irrigation requirements. Therefore, high priority was given for the construction of large dams and other hydraulic structures, mainly in the eastern and north-eastern region of the country. With the construction of increasingly higher dams involving complex geological, tectonic and seismic conditions, posing new design concepts / challenges, the use of Instrumentation has greatly increased, which supplements the additional design information.

Moreover, dam failures in various parts of the world have greatly stimulated interest in measurement of parameters as a means of ensuring the safety of structures. In India there are more than about 5300 large dams and 80% of which are more than 25 years old. The safety of these ageing dams is an upcoming area of concern. Appropriate instrumentation is the prime requisite for monitoring the behaviour of a dam both during construction as well as operational life.

Proper selection and installation of instruments may help in getting an overall idea about the behaviour of the structure. However, lack of well organised system for collection, documentation and analysis of data are the main constraints encountered at present. As a result, it has been experienced that the preparation of structural behaviour reports has not achieved the desired level, though the structure has been instrumented.

Further, with the advent of numerical methods, the near real simulation of actual conditions existing in the body of the dam is possible. Instrumentation data goes a long way in proving such models and extrapolating the results generated out of such simulations. This aspect becomes all the more important in safety evaluation of existing structures where simplified design methods do not represent the real situation in the field.

The literature on instrumentation based on practices world over is available and is very useful in understanding of the overall dam instrumentation aspects. In India, several Indian Standard codes and CWC Guidelines for Instrumentation of Large Dam and Technical Specifications of Hydro-meteorological, Geodetic, Geotechnical and Seismic Instruments are available. The need was felt for preparation of a comprehensive manual based on the Indian Standard Codes and CWC Guidelines for reference and use by Dam Owners/ Project Authorities and all those associated with dam instrumentation. This manual, therefore, is specifically intended to be useful for designers and field engineers.

The Manual includes chapters on Introduction, Instrumentation Planning for various types of structure including Parameters to be monitored, Types of Instruments, Typical Specifications of Instruments, Installation of Instruments, Instrumentation Data Collection, Processing, Analysis and Presentation, Archival and maintenance of data and recommendations intended to be useful for designers and field engineers.

CHAPTER - 1 : INTRODUCTION TO DAM INSTRUMENTATION

1.1 History

Dams are being built for various purposes for more than 2000 years. The sizes of dams have increased and reservoir capacities have multiplied, over the years. Physical and visual inspections were part of these early projects from construction, initial filling and then through years of project operation. Instrumentation and measurement system came later. The earliest recorded use of geomechanics in Water Resources Structures seems to be in 1853, when topographical readings were taken on the Grosbois Masonry Dam in France, built between 1830-38, to measure displacement of its crest. Since then, the practice of topographical measurements for masonry dams was started and became a common practice.

In India, in the late 19th century, open standpipe Piezometers were used to study seepage flows under irrigation dams built on alluvium. In 1907, this type of instrument was employed by English engineers to determine the free surface of the nappe over a homogeneous earth dam.

In 1916, a sensor consisting of a stretched wire to measure pressure in concrete and earth dam was designed by Roy Carlson. The variation in electric resistance in terms of relative movement of two anchoring points was measured. In 1922, a major instrumentation programme on the arch dam was launched in US wherein inclinometers, based on variable resistance sensors, were used.

In the field of instrumentation, an important milestone was marked in 1931 when vibrating wire sensors, then called Acoustic Indicators, were patented in France. Subsequently, 17 vibrating wire extensometers were installed in Bromme Arch Dam (1930-1932) in France. However, the first major monitoring programme was carried out on the Mareges Dam (1932-35) in France, in which 78 extensometers were placed in the body of the arch and 40 in the abutments. Vibrating wire sensors have given rise to a whole range of instruments, which are claimed to be very well suited to the severe environmental condition typical in civil engineering.

1.2 General Consideration

Dam monitoring techniques or procedures range from simple well planned visual observation to the installation of sensors right inside the body of a structure. Dam monitoring here refers to the range of techniques and procedures applied in observing the behaviour of a structure from the time it is built, during its initial filling and throughout its useful life.

The term instrumentation is used for monitoring by means of apparatus built around sensors. These instruments may be mobile or permanently mounted in or on a structure. Readings may be taken continuously or intermittently, automatically or manually, and from a remote location or on site.

The instrumentation in dams poses a specific challenge from the point of view of ruggedness and the ability to survive hostile environments. This poses special requirements that are more difficult than other instrumentation applications.

Earlier, Instrumentation was not usually specified in project plan and was installed only when problems were encountered during construction. Instruments were designed, built and installed for a particular job. However, the concept has now been changed with time. Now a days, Instrumentation is to be specified in each project plan and is being recognized not only as a necessity but also a useful tool to the designers and construction and maintenance engineers for monitoring the safety of the structures.

In the present scenario, most of the viable sites for dam construction have been exhausted. The engineers are now taking the challenges to build dams on difficult sites as well to cope with the domestic and industrial need of water. This necessitates adopting most advanced analytical design techniques which can be verified by instrumentation and thus instrumentation plays an important role in this regard.

Health of the dams needs to be monitored properly to ensure their safety. Proper planning of instrumentation helps in gathering valuable information which enables to assess the performance and continuing assurance of the safety of the dam during construction, first filling of the reservoir and during long-term operation of the dam. Hence, the safety of a dam to an accepted level is very important and monitoring of structural behaviour of the dam, by instrumentation is essential. Information provided by instruments yields a better understanding of the response mechanism of the structure to the various stresses to which it is subjected. This leads to building of better designed, safer dams.

As per the Dam Safety Act, 2021, a “specified dam” means a dam constructed before or after the commencement of this Act, which is,—

(*i*) above fifteen metres in height, measured from the lowest portion of the general foundation area to the top of the dam; or

(*ii*) between ten metres to fifteen metres in height and satisfies at least one of the following, namely:—

- (*A*) the length of crest is not less than five hundred metres; or
- (*B*) the capacity of the reservoir formed by the dam is not less than one million cubic metres; or
- (*C*) the maximum flood discharge dealt with by the dam is not less than two thousand cubic metres per second; or
- (*D*) the dam has specially difficult foundation problems; or
- (*E*) the dam is of unusual design;

(The same definition as above was earlier given to “Large Dams” and the term Large Dams has been used in the earlier Guidelines and also in National Register of Large Dams, 2019 published by CWC. The term Large Dam is commonly used in place of the Specified Dams)

In India, there are about 5334 specified dams and 411 are under construction. In general, the status of dam instrumentation in the country is quite poor. Very limited dams have meaningful and operational dam instrumentation to monitor the behaviour of dam.

1.3 Purpose and Need of Instrumentation

Dam safety monitoring is a common safety requirement. Catastrophic dam failure will threaten life and property downstream. The safe functioning of a dam is an important matter of economic benefit and public safety. The long-term performance of a dam is a necessary factor in the evaluation of dam safety. Diurnal and seasonal effects, changes in hydrostatic pressure and related water seepage, affect the health of dams. Wall deflection, settlement and heaving, the rate of water flow, seepage, temperature, vibration, stress, strain and other significant parameters require proper monitoring to detect changes in the performance of the dam.

There are many reasons for installing instrumentation in both new and existing dams. Each dam has a unique situation and requires an individual solution for its instrumentation. The fact that some existing dams have only minimal or no instrumentation at all is not an adequate reason for installing instrumentation.

The primary purpose of instrumentation is to supply data to aid in evaluating the safety of a structure by collecting quantitative data on its performance and by detecting problems at an early and preventable stage. Instrumentation for proper monitoring and evaluation are extremely valuable in determining the performance of a dam.

A secondary purpose is to enable comparison of actual behavior with predicted behavior, which verifies design adequacy and helps gather useful information for refining the design of similar structures in the future.

Therefore, effective instrumentation can play a vital role in the ongoing assessment of a dam's performance, can provide valuable information concerning the safety of the dam, and can help to improve dam design in the future.

The instrumentation needs can further be classified into the under mentioned general categories:

- ***Diagnostic:*** Verification of design, verification of suitability of new construction techniques, diagnosing specific nature of adverse event and monitoring the in-service performance of a structure, etc.
- ***Predictive:*** For predicting behaviour of the structure.
- ***Archival:*** To form a cumulative record of the behaviour of a structure and thus create a data bank that can be used in the future.
- ***Research:*** Advancement of the state- of-the-art.
- ***Public:*** To enhance public relation by assuring the continued safety of the structure.

(i) Diagnostic Needs:

In the present scenario, construction of dams is becoming increasingly expensive. An over conservative design on an unfavourable geological substrata could result in enormous expenditure which could be avoided by appropriate instrumentation programmes to ensure feedback of useful data on the behaviour of the structure and the substratum, thereby enabling the designer to produce a design based on realistic data which would be technically sound and economically viable.

It is a common practice to proceed with construction using the “observational method”. Instrumentation often plays a major role in observations during construction. It enables engineers to determine the stability and adequacy of the design as the construction progresses. Information gathered from instruments also helps to modify purely theoretical treatment by incorporating the effects of actual field conditions.

After construction comes the stage for initial reservoir filling. In general, the objective of instrumentation is to provide a planned programme with adequate time for monitoring and evaluating performance of the dam and its foundation, as the reservoir is being filled for the first time. The frequency of reading embedded and mounted instruments is much more, especially in the first year of reservoir filling. The monitoring required is more stringent for embankment dams as compared to concrete dams.

Once the dam is in operation, it is essential to verify the long term performance of the structure not only to ensure its safe operation but also to improve upon the state-of-art of design for future dams.

Verification of stability of new construction techniques, diagnosis of the specific nature of an adverse event and verification of continued satisfactory performance etc. justify use of instruments for diagnostic reasons.

(ii) Predictive Needs:

Information yielded by instruments are important for informed, valid predictions of future behaviour of the dam. Such predictions include satisfactory performance and severe future distress which may necessitate remedial action.

(iii) Archival Needs:

Authenticated instrumentation data are very valuable for yielding information for resolving possible conflict, more particularly when the construction activity is likely to affect the adjacent structures and helps in quantifying the safety parameters.

The settlement gauge data may be used for deciding the final bottom of the fill for making the exact payment for the fill quantities in the case of embankment on soft foundation. Moreover, instrumentation technology can safeguard construction engineer from public concern about the construction of a structure as per design.

(iv) Research Needs :

Studying the performance of a structure and instrumentation data affords a better understanding of the complexity of the many forces acting on the structure. Such research works have led to advances in construction techniques, innovative design concepts and to a better understanding of failure mechanism.

Comparison of actual observations with assumed conditions. This will provide an opportunity to adjust design criteria based on reliable data. For example, the mandatory installation of settlement and pore pressure measuring devices for embankment dams and their routine observations right from the construction stage are indicators of the importance of instruments in determining the actual settlement during construction and dissipation of construction pore pressures of the embankment, with a view to comparing similar parameters assumed in the design. A wide difference in the assumed and observed values of settlement and pore pressure may call for either a change in the construction procedure or an adjustment of the design criteria at an early stage.

Similarly, for concrete gravity dams, it is very important to know the thermal variations in the dam during its construction which enables to determine whether the concrete setting process is normal or otherwise. To achieve this purpose, temperature measuring devices are embedded within the dam body and also mounted on the surface according to a pre-determined plan for useful observations. Any abnormal setting process indicated by temperature observations may lead to a change in the concrete lift height or changes in the treatment of aggregates before concreting or of the mass concrete during curing.

(v) Public Needs:

The systematic instrumentation programme for monitoring the activities of the structure, during construction as well in operational life, will enhance the safety of the project and will minimise adverse events. The distressed locations can easily be identified for carrying out necessary remedial measures, if required. In the event of a warranted situation the competent state authority/ downstream inhabitants can be informed about likely damages and sudden releases of water. This helps to build up the confidence in the public in support of early completion of the project.

Generally, the inhabitants downstream of a water-retaining structure are always worried about likely inundation due to sudden release of water, without proper warning, in the event of failure. Hence, continued monitoring of a structure by instrumentation will enhance public relations by ensuring continued safety of the structure.

1.4 Philosophy of Instrumentation

Dams are expected to safely withstand, over many years, the potentially enormous forces created by impounded water. Considering the effects of a dam failure in terms of loss of life, damage to property, public welfare and negation of planned benefits of the project, it is imperative to have the means for gathering information to assess the performance on a regular basis for assurance of safety of the dam during construction, first filling of the reservoir and during long-term service operation. The most important objective of an instrumentation monitoring programme is to provide structural behaviour information to complement an adequate dam safety inspection and surveillance programme. Study of structural behaviour provides an important aid in modifying purely theoretical treatment, so as to include the effect of actual field conditions

Ideally, instruments should have the following characteristics:

- Sufficient accuracy
- Long-term reliability
- Low maintenance requirements
- Compatibility with construction techniques and
- Low cost and Simplicity

Before starting a monitoring program, the roles and responsibilities of all involved in the design of equipment, in its acquisition, and in the reading, maintenance, and interpretation of data must be established. These positions must be adequately staffed and funded.

All the officials concerned with the instrumentation monitoring program must be well trained in what is being monitored and why. Personnel, who realise the importance of their efforts, will perform better. It is not sufficient to explain "how to do a task", it should be to explain "why" because a mistake anywhere in the process can render the data meaningless. The meaningless data can be worse than no data at all because it may lead to erroneous actions being taken. A large percentage of anomalies are caused by instrument or human error. Personnel responsible for instrumentation must be trained in determining whether the instrumentation is functioning satisfactorily or otherwise. This may require backup systems and periodic maintenance or calibration. Data should be acquired by trained and skilled personnel.

The entire instrumentation effort should be a meticulous effort because even one instrument reacting anomalously can be of the utmost importance. Anomalous behaviour cannot be ignored just because it occurred for only one instrument.

The question of number, type and location of instruments at a dam can be addressed effectively only by the fortuitous combination of experience and common sense. The instrumentation system design must be conceived with great care and with consideration for the site-specific geotechnical conditions at the dam.

Placement of instruments in hydraulic structures requires certain measures which are different from routine construction procedures. Special precautions are needed to ensure that the cables are not damaged by construction equipment and unskilled workmen.

1.5 Visual observations

Visual observation of all structures should be made in conjunction with instrumentation monitoring to adequately assess the safety of a dam. Visual observation can readily detect indications of poor performance, such as offsets, misalignment, bulges, depressions, seepage, leakage, and cracking. More importantly, visual observation can detect variations or spatial patterns of these features. Most visual observation provides qualitative rather than quantitative information, while instruments provide detailed quantitative information. Visual observation and instrumentation data are natural complements and when used together, they provide the primary means for engineers to evaluate the safety of a dam.

Instrumentation and monitoring, combined with vigilant visual observation, can provide early warning of many conditions that could contribute to dam failures and incidents. For example, settlement of an embankment crest may increase the likelihood of overtopping; increased seepage or turbidity could indicate piping; settlement of an embankment crest or bulging of embankment slopes could indicate sliding or deformation; inelastic movement of concrete structures could indicate sliding or alkali-aggregate reaction. Conversely, lack of normally expected natural phenomena may also indicate potential problems. For example, lack of seepage in a drainage system could indicate that seepage is occurring at a location where it was not expected or contemplated by the designer.

Instrumentation and monitoring must be carefully planned and executed to meet defined objectives. Every instrument in a dam should have a specific purpose. If it does not have a specific purpose, it should not be installed or it should be abandoned.

1.6 Minimum Desirable Instrumentation

There is no simple rule which can determine the number of instruments, their exact type or location. Their determination remaining primarily a matter of experienced judgement.

The minimum recommended instrumentation is limited to that which clearly provides useful information for evaluating dam safety and is also readily installed and monitored. Minimum instrumentation should be located where it will provide data that are representative of the entire structure. While deciding the minimum instrumentation to capture the important critical data, the failure mode for that particular structure should be considered.

Following criteria can be adopted for minimum instrumentation in dams:

(1) New dams should be designed to contain an appropriate number of instruments conforming to state-of-the-art and of desired quality and should be optimally located. This will help to assess the safety of dam on a long-term basis consistent with engineering design and economic constraints.

(2) The existing dams should be retrofitted with instrumentation as dictated by relative need on a site specific basis.

The minimum instruments to be installed will be governed by the stage of the project (existing dam or new/ proposed dams). In case of the proposed dams, it is easy to install all the instruments as per the provisions of the IS codes/ Guidelines or as per the design requirement. Hence, instrumentation to monitor all the parameters such as temperature, strain, no-stress strain, uplift, displacements, pore pressure and seepage in dams may be installed as per the requirement or the provision of the IS codes or guidelines. In case of existing dams, there is practical limitation of installation of instruments maintaining the structural integrity of the dam. Therefore, minimum instrumentation may be installed as per the condition of the dam without compromising with the structural safety. In India, most of the existing dams, however, do not have adequate instruments or current instrumentation systems may not be in good condition.

Further, section 32 of the Dam Safety act, 2021 specifies that, (1) Every owner of a specified dam shall have a **minimum number of such instrumentations** at each specified dam, and installed in such manner as may be specified by the regulations for monitoring the performance of such dam.

(*2*) Every owner of the specified dam shall maintain a record of readings of the instrumentations referred to in sub-section (*1*) and forward the analysis of such readings to the State Dam Safety Organisation, in the form, manner and at such interval as may be specified by the regulations.

Seismic instruments like Strong Motion Accelerograph/structural response recorders are also installed in dams located in high seismic zones.

The instrumentation alone is not a complete safeguard. The number of devices installed is less important than the selection of proper type of instruments, their location at critical points and intelligent interpretation of data.

The Instrument Planning for various types of Dam Structures (Concrete Gravity dam, Embankment dam etc) has been covered in the subsequent Chapter.

1.7 Cost Component of Instrumentation:

Though the actual cost of instruments may be relatively low as compared to the cost of structure itself but they can be very time consuming and expensive to install, measure and analyse data. It is, therefore, important to limit the number and type of instruments to be installed.

The cost of instrumentation is made up of instruments including junction boxes, cables, data acquisition system, readout sets, personal computers and their essential installation, reading and interpretation. It is therefore essential that a realistic estimate for instrumentation is implemented in right earnest and is not allowed to suffer due to the paucity of funds or insufficient provisions in the estimate.

The process of reading of instruments and interpretation of data has to be initiated immediately after these instruments are installed and continued throughout the construction period. It is therefore essential that sufficient provision exists in the estimate for trained engineers and staff during the construction period also.

The cost of instrumentation should preferably be based on prevailing rates. After assessing the requirements of instrumentation, the cost may be worked out realistically, covering all aspects of reading and interpretation.

1.8 About this manual

In India, several Indian Standard codes related to Dam Instrumentation and CWC Guidelines for Instrumentation of Large Dam, Technical Specifications of Hydro-meteorological, Geodetic, Geotechnical and Seismic Instruments are available. The need was felt for preparation of a comprehensive manual based on the Indian Standard Codes and CWC Guidelines for reference and use by Dam Owners/ Project Authorities and all those associated with instrumentation. This manual, therefore, is specifically intended to be useful for those.

The Manual includes chapters on Introduction, Instrumentation Planning for various types of structure including Parameters to be monitored, Types of Instruments, Typical Specifications of Instruments, Installation of Instruments, Instrumentation Data Collection, Processing, Analysis and Presentation, Archival and maintenance of data which intended to be useful for designers and field engineers.

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CHAPTER-2: INSTRUMENTATION SYSTEM PLANNING FOR SPECIFIC DAMS AND APPURTENANT STRUCTURES

2.0 INTRODUCTION

The main purpose of instruments installed within the dams is to study whether the dam is behaving according to design predictions. The collected data may also help in determining the rehabilitation measures for the dam, enhancement of safety of existing dams and the design approach for new dams. Requirements for measurement depend on the type of information desired. Instruments may be so selected and placed to measure known critical features of the dam. However, for purposes of comparison, a few instruments may also be placed where "normal" behavior of the dam is expected. In the case of a new dam, at least two sections may be monitored, including the deepest and the most critical section. The number of measuring points depends on the type, size, and complexity of the structure being monitored.

Instrumentation system planning is therefore as important and critical as other features of a dam. Careful attention should be given to planning an instrumentation system to ensure that required information is obtained both during construction as well as during the life of the structure. The requirements of the system and the procedures to be used for analyzing the observations should be formulated in detail and selection of measuring devices and their location chosen to meet these requirements. A systematic approach beginning with setting up the objectives and ending with predetermined actions based on the data obtained may be followed. The planning and specification of a comprehensive set of instruments for monitoring the behavior of a dam involves a logical sequence of following decision steps:

- Define the primary purpose and objectives of instrumentation.
- Determine the measurements that are appropriate for the dam under consideration.
- Decide on the locations and the numbers of measuring points for the desired data.
- Take a decision on the time period for which the instrumentation is to be operational, i.e. long-term or short-term monitoring.
- Determine the best sensing mode in relation to the desired degree of response and required accuracy.
- Select the hardware that is appropriate to the task as defined as above.

A practical approach for achieving the desired objectives may be followed, wherein an ideal instrumentation plan may be drafted in the first instance and then progressively the less necessary provisions may be eliminated until an adequate, balanced and affordable plan gets evolved.

2.1 CONCRETE AND MASONRY DAMS: PARAMETERS TO BE MONITORED

No general rule can be given for the type of measurements to be made at dams as they are of many kinds, have different site conditions and have different problems.

There are two main methods for executing measurements:

1. With precise instruments that measure displacements of permanent bench marks set up on the surface of the dam, in galleries, in vertical shafts, in tunnels in the abutments, and in the measuring wells in the foundation.

2. With instruments that are built into the dam's body and the appurtenant structures by which the above cited measurements can be carried out.

In the case of concrete and masonry dams, the temperature in the dam's body and foundation, strains and deformations, formation and widening of cracks, the opening of joints, stresses (also in the foundation of arch dams), and pore water uplift pressure are the measured parameters. Therefore, in general, the following typical measurements may be undertaken for the new dams:

- Uplift pressure at the base of the dam at a sufficient number of transverse sections;
- Seepage into the dam and appearing downstream there-from;
- Temperature of the interior of the dam; and
- Displacement measurements – It should include one or more of the following types of measurements
  - Those determined by suspended plumb lines;
  - Those determined by geodetic measurements where warranted by the importance of the structure;
  - Those determined by embedded resistance joint meters at contraction joints where grouting is required to be done.
- Stress
- Strain
- Pore pressure (as distinct from uplift pressure),
- Seismicity of the area and dynamic characteristic of the structure.

The number of devices installed in a dam is less important than the selection of proper types of instruments, their location and intelligent interpretation of the data. Instrumentation should be provided in at least one deepest overflow block and two abutment blocks. Further, the number of instrumented blocks may be increased with the increase in length of dam. ***Figure 2-1*** shows a view of a gravity dam that illustrates instrumentation plan for measuring parameters.

As per IS 7436 (Part 2 : 1997) - Guide for types of measurements for structures in river valley projects and criteria for choice and location of measuring instruments [Part 2: Concrete and masonry dams], following measurements may be made in the concrete and masonry dams.

2.1.1 Measurement of Uplift Pressure

The hydrostatic pressure difference between the reservoir level and the downstream pool or tail water results in an obvious potential for seepage through, around, and under a dam. Such seepage occurs at every dam through joints or cracks in the dam and through joints, cracks or bedding planes in the dam foundation and abutment rock.

It is important to measure these water pressures at various points in the dam foundation and abutments because such measurements can be critical to aid in the detection of presence of excess hydrostatic uplift pressures on the base of dam and other related problems. These measurements also indicate the gradient (upstream to downstream) and provide the means to determine the effectiveness of grout curtains and foundation drainage facilities.

- Measurement of uplift in the foundation is mandatory for all gravity dams. It is important to determine the magnitude of any hydraulic pressure at the base of a dam. The effect of uplift on a dam is to reduce its effective weight on account of resulting buoyancy.

- Uplift pressure measurements should be made at cross sections representing the principal types of foundation strata. Uplift measurements should be done at least at three cross sections in case of small dams and at least at five cross sections in the case of other large dams.

- The cross sections chosen should include one of the deepest overflow and non- overflow sections, and some sections near the abutments. Uplift measuring points on a cross section line should be located taking into consideration the geological features appearing at the cross section so that the effect of such geological features on the uplift picture could be evaluated.

- At any cross section, uplift measurements should be done at
  (a) upstream of the grout line;
  (b) between the grout line and the drainage hole;
  (c) immediately after the drainage hole and

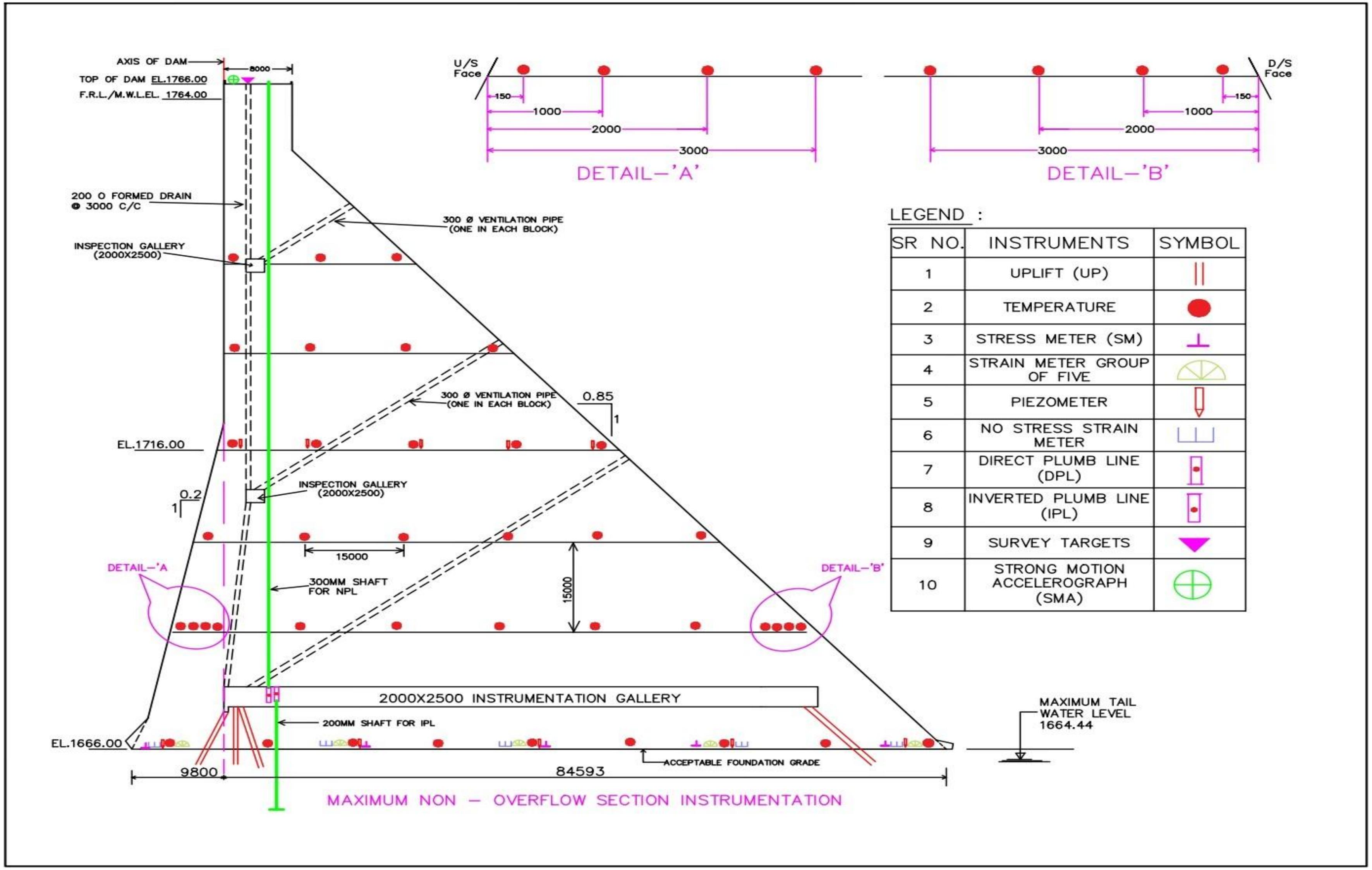

Figure 2-1 Typical Instrumentation Plan for Gravity Dam

(d) at the end of the cross gallery. Spacing between (c) and (d) may be divided equally. In case of large-base widths, a spacing of 20 m may be adopted.

- Uplift pressure cells based on vibrating wire or unbonded resistance wire principle should be used for remote indication applications.

2.1.2 Measurement of Seepage

Seepage is, undoubtedly, the best indicator of the overall performance of a dam because this reflects the performance of entire dam and not just the condition at discrete instrumented points. Any sudden change in the quantity of seepage without apparent cause, such as a corresponding change in the reservoir level or a heavy rainfall, could indicate a seepage problem. Similarly, when the seepage water becomes cloudy or discoloured, contains increased quantities of sediment, or changes radically in chemical content, a likely serious seepage problem is indicated.

- It is customary to provide grout curtain near the upstream face of the dam. Besides, a drainage curtain in the foundation and porous drain in the body of the dam are provided to intercept any seepage that passes through the grout curtain and through the body of the dam respectively.

- Measurement of seepage water along with uplift measurement at the plane of contact of the dam and its foundation will give direct indication of the effectiveness of the grout curtain and drainage curtain and will indicate whether any remedial measures are necessary. The chemical analysis of the seepage water through the foundation drainage system will help in assessing whether any foundation material is being washed out.

- Likewise the quantum of water passing through ungrouted contraction joints or cracks would indicate about the workmanship in general as also any damage that might have been caused to the seals in the contraction joints. The chemical analysis of the water in the case of masonry dam may be indicative of any possible leaching action on the mortar used in the construction of the masonry dam. Corrective measures such as grouting of dam and foundation, besides improving existing drainage or providing additional drainage could thus be planned.

- Wet spots or seepage appearing at new or unplanned locations at the abutments or downstream of a dam could also indicate a seepage problem.

- Measurement of seepage downstream of the grout curtain provides a direct indication of the adequacy and effectiveness of the grout curtain, drainage curtain and functioning of the drains and holes to decide when and where remedial measures may be required.

Seepage measuring devices are required to be installed to measure quantity of seepage through, around or under dams. Drain outlets are commonly used was seepage measurements points. The seepage water should be tested to determine its chemical composition because chemical changes may indicate progressive dissolution, decay or erosion in the dam body, foundation or abutment.

2.1.3 Measurement of Temperature

As temperature is one of the major factors causing stresses in massive concrete structures, therefore, it is necessary to measure it accurately at many places in the dam structures.

(i) Measurement of Temperature during Construction

- For concrete gravity dams, it is very important to know the thermic variations in the dam during its construction which enables to determine whether the concrete setting process is normal or otherwise. For this, temperature measuring devices are embedded within the dam body and also mounted on the surface according to a predetermined plan for useful observations.

- Any abnormal setting process indicated by temperature observations may lead to a change in the concrete lift height, and also changes in the treatment of aggregates before concreting and of the mass concrete during curing.

(ii) Measurement of Temperature of the Dam Interior

- It is necessary to measure temperature in the body of concrete and masonry dams in order to ascertain the nature and extent of thermal stresses and the consequent structural behaviour of the dam and also to ascertain when to undertake grouting of contraction joints that may have been provided for the structure.

(iii) Measurement of Temperature of Reservoir Water and Air

- Measurement of temperature of reservoir water and air is essential for distinguishing the effects of ambient and water temperatures on such measurements as deflection, stresses, strains, joint movements and settlements.

Temperature measurement can be done by either (a) resistance temperature meters or (b) vibrating wire type temperature meters. The resistance temperature meter works on the principle that resistance of an electrical wire is a function of temperature. The vibrating wire type works on the principle that a change in length of vibrating wire results in proportional change in natural frequency.

Location of temperature meters:

Sufficient numbers of temperature meters should be embedded at intermediate points to give a complete picture of the temperature in the body of the structure. The requisite temperature meters should be provided as per following criteria:

- A typical scheme for location of temperature meters would be to place them in 15 x 15 m grid horizontally and vertically in a minimum of one block in the spillway portion of the dam and in other portions depending upon the data required for detailed study of the structural behaviour of the dam.

- A few temperature meters should be placed near and on the downstream face to evaluate the rapid daily fluctuations in the temperature. Temperature meters placed on upstream face as a continuation of the main temperature meter grid will serve to evaluate lake temperatures close to the dam.

- In order to better define the steep thermal gradients which may be more prominent near the upstream and the downstream faces of the dam, it is desirable to place temperature meters at 15 cm, 1 m, 2 m and 3 m from both the downstream faces of the dam in addition to those in the grid.

2.1.4 Measurement of Displacement and Tilt

Measurement of displacement of points either between two monoliths, or between foundation and body of the dam or the displacement of any joint of the dam with respect to the surrounding area will immediately reveal any distress conditions developing in the dam. Measurement of displacement is thus one of the most important factors to be studied while observing the structural behaviour of a dam.

(i) Internal Joint Movement

Concrete and masonry dams are generally built in blocks separated by transverse joints. It is essential to know whether there is any relative movement between two blocks. The movement is likely to be due to differential foundation behaviour. Further, the relative movement of blocks is important from the point of view of grouting of transverse contraction joints. These movements are measured with the help of joint meters. Two types of joint meters are available, namely (a) Un-bonded resistance wire type, and (b) vibrating wire type.

- ✓ Number of joint meters required to be provided in any dam will depend upon the dimension, block layout, provision of transverse and longitudinal joints or transverse joints.
- ✓ In the case of dams built in V-shaped canyon, joint meters should be provided in at least three blocks. One central block representing the deepest and maximum section of the dam and a block each in the abutment portions representing blocks built on steeply sloping section. Joint meters should also be installed in one of the non-overflow blocks or any other block which is representative of these blocks.
- ✓ At a given elevation, the joint meters in each of these blocks should be installed at the centre of the transverse dimensions of the monoliths in the blocks, and should be spaced about 15 m vertically in the height of the longitudinal and transverse contraction joints as the grouting lifts (zoning of joints by provision of metal seal) are limited to about 15 m in height.
- ✓ This spacing may be modified in the top portion of the joint if joint height does not permit the spacing of 15 m for the entire height.

(ii) Surface Joint Movement

Measurement of joint movement at the surface of the locations accessible from galleries is made by detachable gauges with a view to assess the amount of joint opening of two blocks of the dam. These gauges may also be advantageously used for observation of opening or of closing of surface cracks at any location.

Surface joint measurements are made either on the surface or at locations accessible from galleries. The measurements are made by calibrated tapes by fixing two reference points, one each on either side of the joint and by accurately measuring the distance between the two points at certain intervals. This discloses the amount of joint opening.

Portable mechanical gauges are available for this type of measurements. These measurements should be taken at locations corresponding to embedded joint maters so that results can be compared. The surface joint measurements are also taken where surface cracks are noticed.

(iii) Foundation Displacement

Measurement of vertical or horizontal displacement of foundation provides information for taking preventive measures for inclination, distortion, etc. of structures. The data can also be used for studying the elastic and inelastic properties of dam and foundation. Measurement of foundation displacement involves vertical and horizontal displacement of part of foundation with respect to dam. Foundation displacement can either be vertical or horizontal.

(iv) Displacement of One Part of the Dam Relative to other Parts of the Dam

Measurement of relative displacement of two points in a dam is a direct indication of structural behaviour of the dam. The deflection characteristics of a dam observed for the first few years will reveal any dangerous tilt or movement of the dam. These observations are made by regular and inverted plumb lines. The plumb line data together with other supporting data may be used to study the behaviour of the dam.

(v) Displacement of Dam with Reference to Surrounding Area

This measurement gives the absolute displacement of the dam with respect to surrounding area, and is a direct indication of structural behaviour of the dam. Provisions should be made for periodic deflection measurements. Where topography permits, this can be done by theodolite from fixed bases, using either line-of-sight over the top of the dam or by turning angles to targets on the downstream face and at the crest. At concrete dams, the deflections should be consistent with changes in reservoir water surface level and in temperature and should not change appreciably from year to year.

(vi) Measurement of Tilt

Tilt is measurement of rotation in vertical plane. It is normally measured with the help of tilt meter system consisting of tilt meter sensor, tilt plates and indicator. Tilt plates are bonded to the surface of mass of structure under observation. The sensor is oriented on three pegs of tilt plate and senses change in tilt of tilt plate. The portable indicator gives the degree of rotation.

Tilt measurements should preferably be done where plumb line observations are made so that results can be compared and used together.

2.1.5 Measurement of Stress

Direct measurement of stress developed inside the mass of concrete or masonry helps in watching the structural behaviour of dams and their foundations. Any adverse change in stress will indicate distress conditions and remedial measures can be taken. The observation of stress also helps in studying the assumed stresses and actual stresses in dams and this can be used in improving upon the design procedure. Stress meters are being used for measuring the stresses. The stress meter is useful only for the measurement of compressive stress and cannot be used for tensile stress measurement.

- Stress is measured in zones subjected to compression. As the maximum stresses are developed near the foundation both in reservoir full and empty conditions and at a location where height of the dam is maximum, the stress should be measured in the monolith of maximum height.

- There should be at least 5 stress meters in a straight line from upstream face to downstream face and on the horizontal plane. Stresses may also be measured at special locations where high stresses are anticipated or where special information is desired. Stress meters could also be used on the upstream face of the dam for the determination of pressure exerted by silt.

2.1.6 Measurement of Strain

Factors like temperature, chemical action, moisture change and stress result in volume changes, which cause strain in the structure. The measurement of strain, therefore, becomes necessary. As the design of structures is based on stress, it is essential to measure the stresses developed in the structures during its lifetime.

The instruments available for measurement of stresses can measure only compressive stress and not the tensile stress. Further, the stress measuring instruments are more expensive and delicate than strain meters and hence, it is a common practice to measure the strain and to calculate from it the developed stress. Therefore, as mentioned above, the strain may be measured at all the locations where stress is to be determined.

Strain meters can be generally divided into two classes, namely:

(a) Surface strain measuring devices meters which can be used on surface and at accessible location. They are useful for superficial and short-term strain measurements.

(b) Embedded type instruments that can be embedded into the body of the structure. They are useful for long-term strain measurements for finding out the structural behaviour of dams.

2.1.7 Measurement of Pore Pressure

Since large concrete and masonry dams are provided with internal formed drains located near the upstream face, a record of pore pressure development and its variations would indicate the effectiveness and adequacy of these drains. Any sudden unusual increase in the pore pressures will be indicative of choking up of these internal drains and any unusual reduction from the normal would indicate the possibility of formation of cracks or establishment of flow channels in the body of the dam.

- These measurements may be made normally at 10 to 15 m spacing along the width of the dam. Near the bottom, the pore pressure may be measured at the contact plane of foundation and concrete, or just above the foundation or in the foundation by drilling holes, as may be required by the design.

- A second row may be installed at one-third or half the height of the dam.

2.1.8 Measurement of Water Level on Upstream and Downstream Side

This measurement is useful for calculating the water pressure on the upstream face and downstream face of the dam.

Automatic water level recorders are installed on the reservoir to record the water level fluctuations. The measurement of water level is essential for establishing relation between the water level variations and the structural parameter variations being monitored. The water level measurement is a routine measurement as a part of hydrological observations for the dam project.

2.1.9 Seismicity of the Area and Dynamic Characteristic of the Structure

In order to assess the performance of the dam in the event of an earthquake event, the structural response of the dam has to be recorded continuously during such an event. Also, the dam being a large structure, the response depends on ground motion characteristics of the surrounding area and path of propagation of seismic waves through the region. Thus, the regional assessment also becomes necessary. For these purposes, seismic instrumentation is required and hence a seismological laboratory may be established near the project site.

The provisions of seismic instrumentation and measurement program depend upon the seismic risk for the dam site and the size of the dam. Seismic instrumentation generally comprises of seismographs and micro earthquake recorders for general seismological study purposes and Strong Motion Accelerograph and structural response recorders for assessment of structural response of the dam. Establishment of seismographs and micro earthquake recorders generally needs advice of an engineering seismologist and also identification of specific sites with low ambient vibration noise levels. Choice of installation locations need special consideration for capturing the general behaviour of dam monolith.

Strong motion instrumentation are generally provided on near the base of the dam (in a recess provided in the foundation gallery) as well as at the top of the dam. It is preferable to provide them in one vertical plane section of the dam in at or near deepest foundation levels. If the height of the dam exceeds 100 m, these may also be installed near the mid-height of the dam.

The instruments located in the foundation gallery are meant for observing the input ground motion in the event of major earthquake. The instruments located at the top of the dam are expected to provide information about response of the structure to the earthquake.

Regional level seismological networks are being operated by many expert agencies like IMD, NGRI etc. in the country. The seismological network established for the dam should be capable of sharing data with such regional and national level data bases.

2.1.10 Other Measurements

The following other measurements which would aid in interpretation of the main instrumentation data are also necessary.

2.1.10.1 Rainfall Measurement

Rainfall measurement is routinely carried out as part of hydrological observation. Rainfall measurement is important during construction and operation of the dam.

2.1.10.2 Wave Height and Ice Effect

Measurement of height of wave and effect of ice are also useful for interpretation of results of structural behaviour of the dam. The wave height information is important to assess free board of the dam.

2.1.10.3 Measurement of level of Silt Deposit at the Upstream Face of the Dam

This would be useful for determining the pressure due to silt deposit on the upstream face of the dam.

2.1.10.4 Other Meteorological Measurements

Other meteorological measurements, such as of wind velocity, wet & dry bulb temperatures, may also be made.

A simple, portable, battery operated readout unit with 4-digit LCD display should be used. Calibration data for each transducer should be provided when a simple readout unit to read frequency is used, for converting the frequency readings to relevant engineering units. Readout units with facility to read the relevant engineering units directly on the display can be used in place of the frequency readout units.

2.1.11 Auxiliary data to be collected

Data to be kept of construction/operation stages:

The following data of construction/operation stage should be kept:

- Concrete or masonry placing diagram, showing lift placement date, placing temperature and lift thickness; type of method and duration of curing;
- Cooling arrangements, if any, and their details;
- Final rock elevations and unusual geological features; and
- Record of joint grouting operations.

Data to be kept from Control Operations

The following data of control operations should be kept:

- Cement content; water-cement ratios; aggregate grading; amount of entrained air; admixtures used; if any;
- Physical and chemical properties of cement, including heat of hydration;
- Chemical and physical properties of aggregates; and
- Maximum and minimum air temperatures.

Laboratory Data

The following-laboratory data should be collected:

- Specific heat; conductivity; diffusivity; thermal coefficient of expansion dynamic and static modulus of elasticity; creep; compressive, flexural and tensile strengths of concrete;
- Similar properties for masonry to the extent possible;
- Specific surface of cement used for joint grouting and properties of pozzolana, if used; and
- Data of Water Samples.

2.2 EMBANKMENT DAMS (EARTH AND ROCKFILL DAMS)

Earth dams differ from masonry and concrete dams due to relatively greater deformability and higher permeability of earth masses (excluding plastic clay core). Strains and displacements in earth dams are therefore much bigger, hence comparatively simple instruments can be used for measurements of strains and displacements. Distribution of stress in earth dams is more complex and the design analysis is based on radical simplification of the stress pattern and shape of rupture planes. Consequently, stress measurements require considerable judgment in interpretation. Seepage is of greater significance as it can cause internal erosion as well as an increase in pore pressure resulting in instability.

As in the case of gravity dams, the number of devices installed in a dam is less important than the selection of proper types of instruments, their location and intelligent interpretation of the data. Instrumentation should be provided in at least one deepest overflow block and two abutment blocks. Further, the number of instrumented blocks may be increased with the increase in length of dam.

In general, where dam lengths are more and foundation strata varies along the length, location of instruments at two or three sections should be considered. Installation of instruments should be made under constant surveillance of a qualified responsible individual. Measuring instruments for pore water pressures and movements should be installed in proximity so that analysis and interpretation of dam is meaningful. Suitable access should preferably be available for taking measurements throughout the year. Instruments should be guarded against damage or destruction by construction operations.

The installation should be at critical locations where design considerations show weak zones. Soft Clays and fissured clay in the foundation are particularly susceptible to long-term movements and need careful watch. By means of surface surveys, it may be possible to locate areas in which tension of compression is developing, especially in earth dams, which may help in locating incipient slope instability. While locating a movement device, it should be kept in view that maximum horizontal movements generally occur at mid- Slopes and maximum vertical movements occur at mid height of the structure.

Generally, the same types of instruments are suitable for earth and rockfill dams. For the latter, however, graded material is used between the rockfill and the instrument so that the instrument does not get damaged by the rock pieces.

2.2.0 Parameters to be monitored

No general rule can be given for the type of measurements to be made at dams, as they are of many kinds, have different site conditions and have different problems.

As per IS 7436-1 (1993): “Guide for types of measurements for structures in river valley projects and criteria for choice and location of measuring instruments, Part 1: For earth and rockfill dams” the following has been specified:

- From the consideration of usefulness of data obtainable, no instruments except for seepage, rainfall and reservoir water levels are required for dams up to **30 m** height. Although this limit may seem superfluous, the actual requirements “may be best guided by consideration of foundation and construction materials, the importance of the structure, design methods and criteria adopted.

- An earth or rockfill dam with weak soils in the foundation of embankment is to be treated as a special case irrespective of its height and instruments should be provided to suit the observation requirements from the points of view of safety and collecting data for future similar designs.

- Where dam lengths are more and foundation strata vary along the length, location of instruments at two or three sections should be considered.

- Measuring instruments for pore water pressures and movements should be installed in close proximity so that analysis and interpretation of dam is meaningful.

However, in general, the following field measurements often needed to evaluate the performance of embankments along with the purpose of monitoring are briefly narrated below:

1. Pore Water pressure
2. Movements/deformations
    i) Internal movement
    ii) Surface movement
3. Seepage / drainage
4. Stresses and strains
5. Seismicity of the area.
6. Reservoir and Tail water level
7. Wave Height
8. Rainfall

The number of devices installed in a dam is less important than the selection of proper types of instruments, their location and intelligent interpretation of the data.

2.2.1 Measurement of Pore Pressure

Excessive pore water pressures in either embankment or in the foundation or in abutments directly affect the stability of the dam. Such measurements can be critical because of possible piping or other seepage induced instability conditions. Therefore, the measurement of pore pressure is probably the most important and usual measurement to be made in the embankments. It enables to measure the seepage pattern set up after impounding of reservoir to know the dangers of erosion/slides in the dam and abutments.

2.2.2 Measurement of Movements

Movements conforming to normal expectations are the basic requirements of a stable dam. Measurement of movements is as important as the measurement of pore pressures. An accurate measurement of internal and external movements is of value in controlling construction stability. Further, both vertical and horizontal movements should be measured. The measurement of the plastic deformation of the upstream and downstream slopes under the cycles of reservoir operation may indicate the likely development of shear failure at weak zones.

i) Internal movement

The measurement of internal movement of dams consists principally of vertical movements and relative horizontal movements caused mainly by the low shearing strength or the long-term creep of the foundation or embankment materials. Internal movements do, of course, result in external movement of the dams crest or side slopes. In general, the need to measure vertical movement increases as dams increase in height and volume, as this results in correspondingly greater settlement than that for dams of lesser height on similar foundations. To provide data, that are readily interpreted, measuring both the vertical and the horizontal components of movement at one or more locations may be necessary.

ii) Surface movement

External vertical and horizontal movements are measured on the surface of embankments through the use of level and position surveys of reference points. Reference points may be monuments designated points on the crest, slopes or toe of the embankment or on appurtenant structures. Detecting surface evidence of slope stability problems during construction is of primary importance. Such evidence includes slope bulging, sagging crests, foundation heave at or beyond the toes and lateral spreading of foundation and embankments.

Thus, in embankment dams, the key movements to monitor include foundation and embankment settlement, and vertical and horizontal deformations within the embankment and its foundation. Embankment movement measuring instruments include settlement sensors, foundation baseplates, inclinometers, extensometers, surface points, and various survey instruments.

2.2.3 Measurement of Seepage

Seepage through, around or below an embankment dam is a valuable indicator of the continuing level of performance of a dam. It may indicate erosion or blocking of downstream drains and relief wells, by increase or decrease of seepage, respectively at constant reservoir conditions. The quantity of seepage entering a seepage collection system is normally directly related to the water level in the reservoir. Any sudden change in the quantity of seepage collected without apparent cause, such as a corresponding change in the reservoir level or a heavy rainfall, could indicate a seepage problem. Similarly, when the seepage water becomes cloudy or discolored, contains increased quantities of sediment, or changes radically in chemical content, it is an indication of serious seepage problem. Likewise moisture appearing at any location on the downstream slope also indicates a seepage problem.

2.2.4 Strains and Stresses

Accurate measurement of stress is difficult as distribution of stress in earth and rockfill dams is complex and is not very successful except in the case of bearing pressures of soil against rigid surfaces like wing walls and firm foundations. Stress measurements require considerable judgment in interpretation as the analysis and design of earth and rockfill dams is based on radical simplifications of the stress pattern and the shape of the rupture planes. A unique relationship does not exist between stresses and strains in a fill dam. However, strain can be indirectly calculated using internal movement/displacement data.

2.2.5 Seismicity of the Area and Dynamic Characteristic of the Structure

As mentioned in section **2.1.9** .

2.2.6 Measurement of Reservoir and Tail Water Level

Reservoir and tail water heads are among the principal loads to which a structure is subjected, the measurement of reservoir and tail water levels is essential for interpretation and realistic assessment of the structural behaviour of the reservoir retaining structure.

2.2.7 Other Measurements

2.2.7.1 *Wave Height*

Records of wave height data along with wind velocity and other pertinent data help in deciding free board requirements more realistically.

2.2.7.2 *Rainfall*

This measurement is necessary for interpretation of pore water pressure and seepage development in earth dams.

2.2.7.3 Data about Material Properties

The knowledge of properties of materials which are relevant to the type of measurement are essential for interpretation of instrument observations.

Figure 2-2 shows a view of an embankment dam that illustrates instrumentation plan for measuring parameters. Further, table 2-1 shows Parameters to be Monitored at Dams and the Suggested Instruments or Observation Techniques to be Used.

Parameters to be monitored at dams and the suggested instruments or observation techniques to be used are shown in **Table 2-1.**

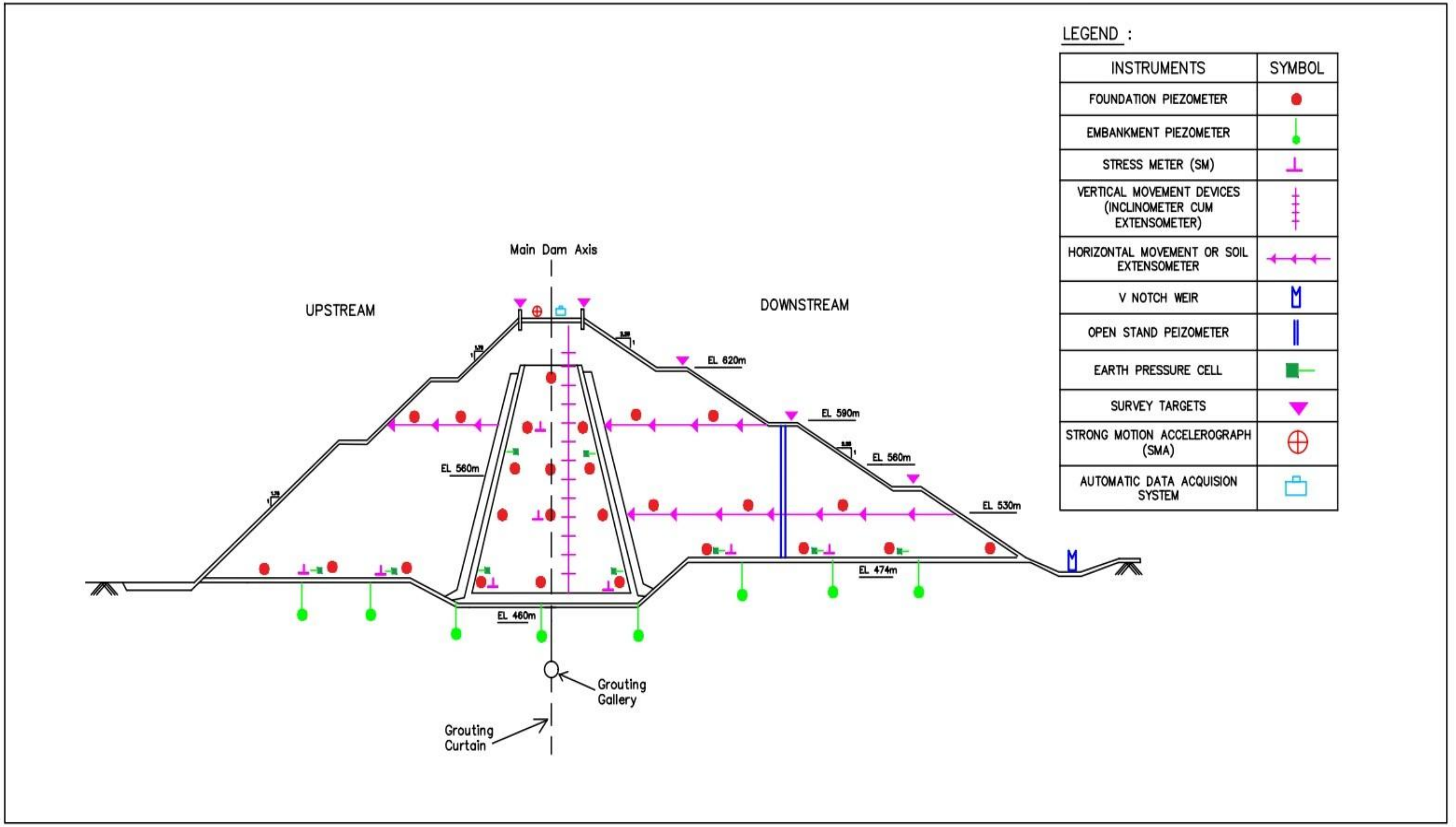

Figure 2-2 Typical Instrumentation Plan for Embankment Dam

Table 2-1: Parameters to be Monitored at Dams and the Suggested Instruments or Observation Techniques to be Used

Type	Feature	Visual observation	Movements	Uplift and pore pressure	Water levels and flow	Seepage flows	Water quality	Temperature measurement	Crack and joint measurement	Seismic measurement	Stress-strain measurement
Embankment Dams	Upstream slope	●	●	●	●	–	–	–	–	●	–
	Downstream slope	●	●	●	–	●	●	●	●	●	–
	Abutments	●	●	●	–	●	●	●	–	●	–
	Crest	●	●	●	–	–	–	–	●	●	–
	Internal drainage system	–	–	●	–	●	●	●	–	–	–
	Relief Drain	●	–	●	–	●	●	–	–	–	–
	Riprap and other slope protection	●	–	–	–	–	–	–	–	–	–
Concrete and Masonry Dams	Upstream slope	●	●	–	●	–	–	●	●	●	●
	Downstream slope	●	●	●	–	–	–	●	●	●	●
	Abutments	●	●	●	–	●	●	–	–	●	●
	Crest	●	●	●	–	–	–	●	●	●	●
	Internal drainage system	–	–	●	–	●	–	–	●	–	–
	Relief drains	●	–	●	–	●	–	–	–	–	–
	Galleries	●	●	–	–	–	–	–	●	●	●
Spillways	Approach channel	●	●	–	●	–	–	–	–	–	–
	Inlet/outlet structure	●	●	●	●	●	–	–	●	●	–
	Stilling basin	●	–	–	●	–	–	–	●	–	–
	Discharge conduit/ channel	●	–	●	●	–	–	–	–	–	–
	Gate controls	●	–	–	–	–	–	–	–	–	–
	Erosion protection	●	–	–	–	–	–	–	–	–	–
	Side slopes	●	●	●	–	●	–	–	–	–	–
Outlets & Drains	Inlet/outlet structure	●	●	●	●	–	–	–	●	●	–
	Stilling basin	●	–	–	–	–	–	–	–	–	–
	Discharge conduit/chan	●	●	●	●	–	–	–	●	–	–

	nel										
	Trash rack/debris controls	●	–	–	–	–	–	–	–	–	–
	Emergency systems	●	–	–	–	–	–	–	–	–	–
General Areas	Reservoir surface	●	–	–	–	–	●	–	–	–	–
	Mechanical/ electrical systems	●	–	–	●	–	–	–	–	–	
	Shoreline	●	–	–	–	–	●	–	–	–	–
	Upstream watershed	●	–	–	–	–	●	–	–	–	–
	Downstream channel	●	–	–	–	●	●	–	–	–	–

Commonly used instruments for various parameters to monitor the performance of Gravity and Embankment Dams are enumerated in ***Annexure - A***

CHAPTER–3: TYPES OF INSTRUMENTS, THEIR USES AND TYPICAL SPECIFICATIONS

3.1 Types of Instruments

There are several kinds of geo-technical instruments that are available to measure physical parameters needed to evaluate dam safety and performance. Most geo-technical instruments consist of a transducer, a data acquisition system and a communication system between the two. Selection of transducer, a data acquisition system and a communication system between the two depends on its requirements. A transducer is a device that converts a physical change into a corresponding output signal. Data acquisition system range from simple portable readout unit to complex automatic system. A brief description of various mechanical, hydraulic, pneumatic, electrical and fibre optic transducers and communication system that are generally used with geo-technical instruments is given in the following sections.

Instruments can be classified into following main categories based on their working principles:

- Mechanical
- Hydraulic
- Pneumatic
- Electrical / Electronic
- Optical and
- Fibre Optic sensors

Initially, mechanical and hydraulic instruments were used extensively for instrumentation. With the passage of time and advancement of technology, pneumatic and electrical / electronic instruments became popular. The mechanical, hydraulic and pneumatic types of instruments are simple, rugged, reliable, cheaper and easy to operate but have lower response and lower accuracy. The mechanical type cannot be read remotely, while pneumatic and hydraulic though can be read remotely, have problems with connecting tubes of blocking and breaking. Electrical types of instruments facilitate easy remote reading, use of data logger and computers in addition to their high sensitivity, high resolutions and accuracy.

Now a day, electrical / electronic types of instruments are increasingly being used in instrumentation of dams and other hydraulic structures. The electrical / electronic type of instruments includes un-bonded resistance type, bonded strain gauge type and vibrating wire type. The un-bonded resistance type of instruments have long-term stability but they suffer from zero drift, cable resistance variation, sensitivity to temperature changes, moisture, movements etc. Their long term reliability is questionable.

Hence, vibrating wire instruments are now increasingly being used for instrumentation. These instruments are reliable, sensitive, accurate, durable and can be used with modern data loggers and computers. Other advantages of vibrating wire instruments are:

- splicing of cable can be performed without any significant impact on the long-term performance;
- cable can withstand stresses due to construction activities; and
- instruments do not need much maintenance.

Principles of working of above type of instruments are given below:

I) Mechanical

This is a device that converts physical change into a corresponding mechanical output signals that can be read either by a dial gauge, simple scale or vernier device, i.e. micro meter or calipers or any other such device. A dial indicator is used to convert the linear movement to a more visible movement of a pointer that rotates above the dial. This arrangement includes rack and pinion and gears.

II) Hydraulic

This device is filled with de-aired hydraulic fluid. Pressure is supplied to one side of flexible diaphragm in the transducer. When this pressure equals the cell pressure on the reverse side of a diaphragm, the valve opens and allows flow along the return line to a detector in the readout unit.

III) Pneumatic

This works on the same principle as of hydraulic instruments except of filling component which is normally nitrogen in place of de-aired water.

IV) Electrical / Electronic

Most of the instruments work on strain measuring technology. Stress meters, strain meters, pore pressure cells, temperature meters, joint meters, tilt meters, deformation meters etc. fall under this category. These Instruments can be classified as follows on the basis of their working principle.

- **Resistance Type**

These work on the principle that the elastic resistance of a metallic wire changes proportionally to change in its length. In this type of instruments the reading at the remote reading station is affecting by the length of lead cable and ingress of moisture into the cable. Besides, contact resistance of switches and plugs also affect the reading in this type of instruments.

The unbonded resistance wire types of instruments have long-term stability and are in use extensively. Bonded strain gauge type of instruments should preferably not be used for embedded applications. These may be used only on surface and accessible locations and for short-term observations. They are unsuitable for long-term application.

- **Vibrating Wire Type**

These work on the principle that when plucked, frequency of a stretched wire depends on the tension in the wire and hence on the strain. As the basic measurement is in the form of frequency, the observations can be relayed over long distances through cables without affecting their accuracy. In the case of frequency transmission, the cable resistance and the contact resistance of switches and plugs do not influence the results. As the calibration constant is given by the geometric dimensions of the vibrating wire, they remain unchanged over unlimited time and calibration constant determined in the factory remains always valid. Besides, in such instruments high stability of zero point can be obtained by carrying out ageing process in the factory.

Vibrating wire type instruments are not sensitive to cable resistance and moisture movement. However, they are influenced by temperature changes but the effect is less significant. They are either compensated for temperature changes or they are supplied with the moistures or correction factor by the manufacturer to compensate the effect.

Vibrating wire type instruments have been used in numerous dams all over the world for decades with good results. As the instruments shall be embedded in the concrete, remote reading facility has to be provided. It is proposed that vibrating wire type instruments may be preferred to other types of instruments.

V) Optical Type:

Optical Theodolite: This instrument is used for standard surveying procedures to measure horizontal and vertical deformations in accessible parts of structures and the ground surfaces using bench marks and surface settlement points. These methods are usually adequate for monitoring and other instruments are used if greater accuracy is needed and measuring points are visually inaccessible to surveying methods. However, whenever possible, even if geotechnical instruments are used, surveying methods are also used for validation of results.

VI) Fiber – Optic Type:

Fibre optic sensors offer outstanding accuracy and repeatability. The new generation of sensors based on fibre optic strain gauge represents a breakthrough in fibre optic sensing.

Using a fiber-optic cable as a sensor, the temperature can be measured along the entire length of the cable. The technology offers the possibility of measuring temperature along cables of a few kilometers in length, continuously and with high accuracy. The method is based on the optical properties of the fiber, which depend on the ambient temperature. A highly-developed measuring technique enables the analysis and evaluation of property changes resulting from a reliable temperature distribution along the fiber. These sensors being completely immune to lighting surcharge provides long-term reliability in dam monitoring.

The quality of instruments is of paramount importance since these are expected to work for very long periods, say 25 - 30 years. More importantly, because embedded instruments cannot be retrieved and repaired if these become defective. In a selection of equipment, service requirements must be carefully weighed. An instrument of rugged construction that gives reasonably accurate results may be preferable to a more precise but delicate instrument.

Ideally, the instruments selected for a given situation should have the following characteristics:

- It should be sufficiently accurate;
- It should have long-term reliability and stability;
- It should have low maintenance requirements;
- It should be compatible with construction techniques;
- It should have low cost; and
- It should be simple but rugged.

3.2 Typical Specifications of Geotechnical Instruments

Specification may be defined as," A statement containing a minute description of an instrument, as the terms of a contract, which cannot be shown in the drawing." A specification is definite, determinate, distinctly and plainly set forth and stated in full and explicit terms. Or simply the specifications should be clear, concise, complete and correct so that there are less chances of misunderstanding, delay or conflict. It should be remembered that the primary need of writing these specifications is to get the instruments of high quality and reliability.

The specifications should be written in the most comprehensive manner possible, based on performance without bias towards any model unless condition dictate the use of a specific model produced by a particular manufacturer. The designer is normally required to specify the instrument type, principle of operation of the transducer (whether resistance type, vibrating wire type, mechanical type, hydraulic type etc.), physical size, limitation, operating environment, readout requirements, power supply, auxiliary equipment, range, accuracy and Calibration test requirements etc.

A specification generally comprises of features related to site condition such as (Operating ambient temperature range, Operating humidity, Altitude etc); Sensor (type, range, resolution, accuracy, requirement of lightening protection etc) and General Features (material, accessories, manuals, installation arrangements etc)

These specifications only define the type of instruments and their operating ranges. As regards the quality of instruments, there is no better way to assess then past experience. The reputation of the manufacturers, the performance reports of the instruments will go a long way to assist their reliability.

The typical specifications of various instruments are placed in Annexure B to facilitate the Project Authorities for guidelines only. No particular manufacturers or their products are being promoted.

3.3 General Requirements of Instruments

The instruments shall be rugged, water tight, sensitive and reliable with long-term stability. It shall have in built arrangement for over-voltage protection and lightening arrester/ grounding. Readings should be unaffected by cable length. The instrument shall be suitable for being connected to data logger / automatic data acquisition system. Requisite accessories e.g. tools, cable connectors etc. along with operation, installation, maintenance manuals, performance certificate, calibration charts etc. shall be supplied along with the instrument.

3.4 Technical Requirements

These stipulations shall apply to all the instruments to be supplied.

- The instruments proposed along with, necessary cable and readout unit form a complete system. All electrical instruments shall be of one particular make and will work on vibrating wire principle.

- All electrical instruments shall be read using a common readout unit.

- The Contractor/manufacturer/supplier shall furnish all relevant details pertaining to the instruments along with the details of any additional accessories / arrangements required which are not specified in the bid but shall be needed for installation and operation of the system. Only such instruments will be considered, which are based upon a proven operating and manufacturing principle and have been embedded and performing satisfactorily for a period of ten years.

- Locations where the instruments and accessories (like cables, multi-core cables, splices, junction boxes and position selectors switches) are to be embedded / installed in galleries may be submerged in the monsoon during the construction period. A certificate to the effect that the instruments and cable joints shall withstand the effect of such submergence without any damage shall be furnished by the Contractor.

- The Contractor shall furnish at least two performance certificates from independent parties to the effect that instruments of the same make and type have been installed and are operative in the concrete / masonry dam / underground caverns in similar or in a more hostile environment has performed satisfactorily for a period of at least 5 years after their installation.

- All the instruments and the readout unit shall be capable of withstanding shocks and vibrations associated during transportation by a jeep on an un-metalled road. During the guarantee period, if any instrument or readout set goes out of order as result of such transportation, the same shall have to be repaired or replaced by the Contractor at his own cost.

- All electrical instruments shall conform to the provisions of I.S. 9000(Part I) - 1977 or its equivalent.

- All electrical instruments shall be installed in the body of a structure in a manner, which is approved by the Project Authority. The pre and post installation checks on the instruments shall be made to demonstrate that the instruments are functioning satisfactorily. If any variation is found, the individual instrument shall be replaced or if installed, shall be removed and reinstalled wherever possible. Specific installation procedures can be agreed upon prior to commencement of work by demonstrating the same at site.

- The instruments shall be individually calibrated in the factory and calibration characteristics shall be furnished with each individual instrument. All necessary correction factors shall also be supplied. The calibration shall be made with actual cable lengths attached. Possible change in calibration parameters shall be specified for the actual length of the cable whenever finalised.

- All calibration constants and correction factors along with the methods of processing the observed readings for obtaining parameters of interest like stress, pore pressures, temperatures etc. in absolute terms of engineering units shall be made available. A worked example of such processing must be supplied with each type of instrument.

3.5 Instruments for various measurements and their specifications

The details of Instruments for various types of measurements and its specification are given below:

3.5.1 Measurement of Uplift Pressure

Measurement of uplift in the foundation is mandatory for all gravity dams and is generally accomplished by uplift pressure pipes which provide a direct indication of the prevailing magnitude of uplift resulting from the operating reservoir heads and consequently the effectiveness of the grout curtain close to the upstream face of the dam and effectiveness of the drainage curtain provided in the foundation apart from checking of design assumptions for its stability.

The device for measuring uplift consists of a pipe installed at the point where uplift pressure is to be measured such that it terminates in a gallery directly above the measuring point, which is generally 1 m below the base of a dam.

The pipes placed upstream of the grout curtain are usually inclined towards upstream face and fitted with a tee section and a -Bourdon-type pressure gauge for observing water pressure and those placed downstream of the grout curtain are read by sounding or with pressure gauge. Last pipe is generally, inclined towards downstream to cover maximum width of the dam.

Uplift pressure pipes are the simplest and most rugged. Only difficulty encountered in case of these pipes is when they get choked. Restoration of choked pipes is possible by drilling a hole through the pipe but if there is a bend in the pipe, drilling is not possible and the pipe has to be abandoned.

For further details, IS 6532 (1972): Code of practice for design, installation, observation and maintenance of uplift pressure pipes for hydraulic structures on permeable foundations may be referred.

The typical specification of uplift measurement system is appended in ***Annexure-B.***

3.5.2 Measurement of Seepage

Small notches and weirs may be constructed at points where seepage is to be measured. From the water level readings at these points quantity of seepage can be computed.

- ***Wiers/notches:*** The weir is preferred if sufficient fall is present in the channel and the quantity of water to be measured is small. These are also used to measure the overall seepage through the dam. The following types of weirs are generally used :

  a) Standard contracted rectangular weirs.
  b) Standard suppressed rectangular weirs.
  c) Standard Cipolletti weirs.
  d) Standard 90' V-Notch weirs.

  The details of the above are provided in IS 14750 (2000): Code of Practice for Installation, Maintenance and Observation of Seepage Measuring Devices for Concrete/Masonry and Earth/Rockfill Dams.

  The typical specification of seepage measurement system is appended in ***Annexure-B.***

- ***Flow meters:*** The flow/velocity meters are preferred when the quantity of water to be measured is comparatively large. The observations should be taken by skilled staff only.

- ***Calibrated Container Devices:*** This method is preferred when the quantity of water to be measured is relatively very small. The device is used to measure the quantity of flow from drains. The device is particularly suitable for measuring the block-wise or reach-wise seepage from the dam.

- Special circumstance may call for other types of flow measuring devices such as current meters.

- Float operated water level sensors using vibrating wire load cell is one type of instrument that should be used for remote indication.

3.5.3 Measurement of Temperature

Temperature measurement can be done by the following:

i) ***Resistance temperature meters:***

The resistance temperature meter works on the principle that resistance of an electrical wire is a function of temperature. Resistance type temperature meters are accurate yet comparatively less costly and hence are extensively used. The operating principle is based on the variations of resistance as a function of temperature. Resistance temperature meters are designed and constructed for embedment in mass concrete for measurement of internal temperatures.

- The coils of resistance temperature meters are wound with suitable platinum or enamelled copper wire wound non-inductively on an insulating core so as to have a definite resistance at predetermined temperature. The temperature meters shall have a fixed resistance change over the temperature change of 0 to 100°C.

- The entire resistance element shall be encased in a soldered brass case to prevent entrance of moisture and the element shall be further protected by filling the inside of the case with joint sealing compound to ensure thermal contact between the coil and the casing. For further details of installation, measurement etc, IS-6524 1972 may be referred.

The typical specification of commonly used *resistance type temperature meters* is appended in ***Annexure-B.***

ii) Vibrating wire type temperature meters:

The vibrating wire type works on the principle that a change in the length of vibrating wire results in proportional change in natural frequency.

A fiber-optic temperature measuring system can be applied at existing dams as well as at new ones (Goltz et al. 2011). The most common application for existing dams is installation of the fiber-optic cable in the dam toe below a refurbished surface sealing or in existing standpipes. In the case of new embankment dams, the cable can be installed during the construction at locations where the monitoring will give the most useful information. Such places are: behind a waterproof facing, or behind an internal dam core made of natural or artificial material.

3.5.4 Measurement of Displacement

3.5.4.1 *Concrete and masonry dams*

Joint Meter

Joint meters are used to measure relative displacement of joints between two adjacent monoliths. The movements may be Surface Joint movement or Internal joint movement.

i) Surface Joint Movement

Measurements of joint movements at surface or at the locations accessible from galleries are made by detachable gauges.

➢ *Whittemore Type Gauge*

The gauge is a self-contained instrument consisting essentially of two frame members bounded together by two elastic hinges for parallel frictionless motion. One 45^0 conical contact point is attached to each member. For taking measurements, the conical points are inserted into the inserts fixed in the drilled holes defining a predetermined gauge length.

➢ *Inserts*

The inserts should be installed on the surface at points corresponding to the locations of joint meters inside the dam. These should also be fixed inside galleries across joints, where these are accessible and at points corresponding to the joint meter locations.

- The inserts are placed in such a position as to indicate opening and closing movements of the joint and any sliding movement of the adjacent block.

- Inserts may be made of mild steel or stainless steel, but stainless steel inserts are recommended though they may be expensive. The mild steel inserts also last well without rusting, if due care is taken, such as cleaning and greasing. Inserts of nylon or any other suitable material may also be used. The insert shall have conical depressions at the centre for providing line of contact with the conical points.

ii) Internal Joint Movement

Two types of joint meters for measurement of internal joint movement are in use namely

(a) Unbonded Resistance Type (Carlson Type), and
(b) Vibrating Wire Type.

(a) Unbonded Resistance Type

The instrument is designed to take advantage of two electrical properties of steel wire, namely, resistance varies directly with temperature and resistance varies directly with tension.

For further details, IS 10434-1 (2003): Installation, Maintenance and Observation of Deformation Measuring Devices in Concrete and Masonry Dams - Guidelines, Part 1: Resistance Type Joint meters, may be referred.

(b) Vibrating Wire Type.

The basic principle of Vibrating Wire Type Joint meter is that change in natural frequency of a stretched wire depends on the change of the tension in the wire. In this instrument one end of the wire is attached to the moveable head of the joint meter by a steel spring and the other end to a fixed point. Any displacement is thus transformed to a variation in tension of the spring and vibrating wire. The frequency of the wire is a measure of displacement between joints. A difference of square of frequencies is proportional to the displacement. The frequency readings are read by the vibrating wire readout which is connected to the gauge by cables.

The main advantages of vibrating wire type joint meter are:

- Easy to read by simple instrument,
- Effects of signal cable resistance, contact resistance, leakage to ground or length of signal cable are negligible; and
- Frequency signal permits data transmission over long distance and thus suitable for centralized observation.

For further details, IS 10434-2 (1996): Guidelines for installation, maintenance and observation of deformation measuring devices in concrete and masonry dams, Part 2: Vibrating wire type joint meter may be referred.

The typical specification of commonly used *Vibrating Wire Type joint meter/crack meter* is appended in ***Annexure-B***

iii) Foundation Displacement

a) Vertical foundation Displacement

- Vertical Foundation displacement is measured through a borehole drilled in the foundation from the foundation gallery by anchoring one end of a thin galvanized wire rope at lower end of the borehole and providing a plumb bob to the other end taken over a pulley. The measurements should be taken at all the points where foundation deformation is expected to be significant. It is preferable to have one measurement each in a grid of 30 x 30 m.

- The plumb bob over a pulley arrangement can be replaced by electrical devices like unbonded strain gauge, vibrating wire strain gauge, LVDT or a potentiometer.

- For the electrical type devices except potentiometer, the wire rope can be replaced by a series of inter-connectable rods. The instrument is known as borehole extensometer.

- The vertical displacement of foundation can also be ascertained by installing joint meters between the contact of the foundation and the dam. The end fixed in the foundation can be mounted on a pipe with its lower end anchored at the bottom of a drilled hole.

b) Horizontal foundation Displacement

Horizontal foundation displacement can be measured by an inverted plumb line. Inverted plumb line consists of a wire; the lower end of which is anchored in the foundation while the upper end is attached to a float, buoyed up by water in a covered tank. The displacement of the wire is measured by a co-ordiscope or microscope and micrometer slide. The inverted plumb line should be installed in the same block in which normal plumb line is installed so that results can be used together. For further details, IS 7436 (Part 2): 1997 may be referred.

The typical specification of commonly used *inverted plumb line* is appended in ***Annexure-B***

(iv) Displacement of One Part of the Dam Relative to other Parts of the Dam

These observations are made by plumb lines. The plumb line data, together with other supporting data may be used to study the elastic behaviour of the dam.

- A plumb line consists of a wire, suspended the structure. The movement of points on the dam through a shaft in the dam, the upper end of the wire being anchored to the body of the dam and the lower end carrying a heavy weight. The oscillations of the plumb line are damped by immersing the plumb weight in oil.

- The deflection of the wire is measured with reference to a reference point. The displacement of wire is measured by a co-ordimeter and co-ordiscope or microscope and micrometer slide.

- One plumb line is installed at the deepest central section and also one each on either side at quarter points of the dam. If the height of the dam ***does*** not change much one plumb line can be installed each at one-third the length of the dam.

For further details, 1S 13073 (Part 1):2002 – Installation, maintenance and observation of displacement measuring devices in Concrete and masonry dams – Part-1: Deflection measurement using Plumb lines may be referred.

The typical specification of commonly used *plumb line* is appended in ***Annexure-B***

v) Displacement of Dam with Reference to Surrounding Area

This measurement is done by surveying methods, namely, either by geodetic method or collimation method.

a) Geodetic method

In the geodetic method, two piers are constructed one on each bank and also on the downstream side of the dam. The piers are used for accurately locating the theodolite for angular measurements. Targets are fixed on the downstream face of the dam and accurate measurements of movements of these targets are made from the two piers with precision instruments. Theodolite stations should be connected to an orientation point outside the influence of the dam and shift of the theodolite stations accounted for in the computations.

The geodetic method has the advantage of measuring absolute displacement very accurately but involves complicated calculations.

Targets should preferably be fixed on grid pattern at locations which detail the horizontal and vertical elements of the structure as adopted for theoretical analysis. Targets should also be located in the blocks containing the plumb line so that the displacements by the two methods can be compared. The actual results of displacement can then be compared with analytical results. For further details, IS 7436 (Part 2): 1997 may be referred.

The typical specification of commonly used geodetic instruments is appended in ***Annexure-B***

b) Collimation method

In the collimation method, a line of sight is established, which remains fixed during the life of the structure. The movement of points on the dam crest are then measured with reference to the line of sight. Collimeter is used for establishing the line of sight. Targets for the observation should preferably be fixed on each block.

vi) Measurement of Tilt

Tilt is measurement of rotation in vertical plane. It is normally measured with the help of Tiltmeter system consisting of tiltmeter sensor; tilt plates and indicator.

a) ***Tilt plates***

These are bonded to the surface of mass of structure under observation. The sensor is oriented on the three pegs of the tilt plate and sense change in the tilt of tilt plate.

b) Portable indicator

The portable indicator gives the degree of rotation. The instrument consists of a base which is permanently fixed in the concrete and a clinometer which is placed on the base. The clinometer is properly placed on the base and air bubble is centered with the help of a micrometer screw. The reading of the micrometer screw obtained at any particular line of observation when referred to the initial reading gives the value of tilt.

c) Vibrating Wire Clinometers

Tilt measurements are also made by vibrating wire clinometers. Vibrating wire type clinometers are either surface-mounted or embedded in the body of the dam. A cylindrical core houses a special pendulum surrounded by damping oil. A vibrating wire is stretched between the pendulum and the core. The instrument works on the principle that any change in the position of pendulum will change the tension in the vibrating wire and its frequency of vibration will change.
Tilt measurements should preferably be made where plumb line observations are made so that results can be compared and used together.

The typical specification of commonly used Tilt meter is appended in ***Annexure-B***

3.5.4.2 ***Earth and Rockfill Dams***

i) Vertical Movement Gauges

a) Surface Markers

Surface marker points consist of steel bars which are driven vertically into the embankment or the ground and embedded in concrete. A reference base line is established on a firm ground outside the area of movement due to reservoir and embankment load. Positions of surface stakes or markers fixed on the embankment are determined by survey with reference to this line. It measures horizontal movements as well.

Surface markers may be established on lines parallel to the centre line of the dam at 50 to 100 m centers. The lines may be at the edge of the top width of the dam, at the edge of berms or at suitable intervals along the slope, at the toe of the dam and at 50 m and 100m from toe if foundation soil is not firm. These may be provided both on upstream and downstream slopes excepting locations on upstream slope, which remain throughout the year below lake water.

b) Cross-Arm Installation

It consists of telescopic steel easing to which are attached horizontal cross-arms at predetermined vertical intervals. As the soil settles, sections of casing are dragged down and these are thus relocated in their new positions by lowering down the casing a probe fitted with retractable claws which engage the bottom of each section in turn or by using an electrical probe. Cross arms are used in order to eliminate any possibility of the easing sections not settling along with the surrounding soil. The details regarding Installation and Observation of Cross Arms for Measurement of Internal Vertical Movement in Earth Dams may be referred in IS 7500 (2000).

c) Hydraulic Device

It is made from two 50-mm diameter brass pipe nipples soldered to a common diaphragm. Pipe caps are secured at both ends of the assembly, which is then mounted vertically on a steel base plate for anchorage in the embankment. The diaphragm separates the upper (air) chamber from the lower (overflow) chamber and encloses a plastic float valve which prevents water from entering the air chamber during the flushing of the lower chamber. Three 8mm outer diameter plastic tubes are embedded in trenches which are excavated to maintain continuous downward slopes to the instrument terminal. The instrument terminal is equipped with a pump, air compressor and high precision pressure gauges.

d) Geonor Probe

It consists of a three-pronged tip connected to a double rod which is lowered down a bore-hole or driven in soft ground to desired depth. When the outer rod is held and the inner rod driven with hammer, the three prongs are forced out into the surrounding soil. The outer rod is then uncovered from, the tip and withdrawn a few centimeters. The top of the inner rod, which remains in contact with the anchored tip is used as a reference point to measure the settlement of the tip. This device is particularly well suited for measuring settlements of soft foundations under-low embankments.

e) Foundation Settlement Measuring Device

It is a base plate placed on the foundation line with a vertical column of steel tubings. The position of the base plate is determined by a surrounding device lowered from the top open end of the steel tubings. For the details regarding installation and observation of base plates for measurement of foundation settlement in embankments, IS 8226 (1976) may be referred.

f) Magnetic Probe Extensometer

This system consists of a magnet/leed switch probe of approximately 15 mm diameter connected to an indicator with a marker connecting cable. Magnetic ***ring*** markers with stainless steel spring parts are installed over a series of PVC access pipes of 33 mm outer diameter and 27 mm inner diameter joined together.

The probes when lowered through the access pipe will give indications in the indicator where the magnet marker rings are located. When settling takes place, the marker rings will move with the soil and the fresh positions of the marker rings indicate the amount of settlements with respect to earlier logged position.

g) Induction Coil Type Extensometers

This induction coil type extensometers consist of an electrical probe made of PVC and having a diameter of 35 mm or 43 mm which houses a primary electrical exit. The probe is connected to an indicator electrical cable. Indicator has a volt/ammeter to measure the voltage/current increase when the primary coil enters a secondary coil, when there is a steel marker ring or plate, it will indicate a current/voltage which could be read through the indicator. Series of marker rings installed over a corrugated PVC pipe installed over a PVC access tube or inclinometer tube should help to monitor the settlement.

Vertical movements may also be measured by using telescoping couplings for connecting the sections of the tubings and noting the positions of the ends of each section by a mechanical latching device, or if metal rings are embedded in the end portions of plastic tubing, by an electromagnetic device.

ii) Horizontal Movement Gauges

a) Cross-Arm Installation

This installation is similar to that described earlier, however, for horizontal movement, instead of cross-arm fixed at different sections, there are two vertical plates at the same level placed at a certain distance apart. The relative horizontal movements between the two cross-arms are measured by transmitting the same by means of a cable in a pair of counterweights, which move vertically in the tubing. A sounding probe similar to that used in measurement of vertical movement installations determines the position of the counterweights.

b) Inclinometers

Plastic or aluminum tubing is placed vertically in the dam with its bottom anchored to firm unyielding stratum. The inclination of the tubing is measured by a sensitive electrical inclinometer, step by step, starting from the bottom of the tubing. Horizontal movements are computed by integrating the movements starting from the bottom, on the basis of changes in the inclination. Each section of tubing is anchored to the surrounding soil mass by fixing flanges or collars to the tubing. Alternatively, when an electromagnetic sounding device is used, the plastic tubing passes through encircling metal discs which are free to move along with the earth mass and the position of these discs are determined by the device.

Horizontal movements may also be measured by running an electromagnetic probe through telescoping plastic tubing laid horizontally across the dam axis.

For details regarding the various displacement measuring devices in earth and rockfill dams, IS 7436 (Part 1): 1993 may be referred.

3.5.5 Stress Meter

Stress Meters are used for determining vertical stresses on the horizontal plane at a section and also for computing strains.

- One of the stress meters commonly used consists of mercury filled diaphragm to which is attached a measuring unit consisting of unbounded resistance-wire strain meter. The stress applied to the mercury filled diaphragm is converted into strain by elastic deformation of diaphragm and is measured by the strain meter. The meter is useful only for the measurement of compressive stress and cannot be used for tensile stress measurement.

- The stress meters or the pressure cell comprise of thick metal flat jack formed from two thin steel plates welded around the periphery, connected to the vibrating wire transducer by a steel tube welded to the short edge of the cell. The transducer is fitted with a long compensating tube, allowing adjustment of the cell volume to compensate for the concrete shrinkage. The flat jack is filled with mercury.

- The manufacturer can provide the stress meters of alternative design. However, in such case, a full technical justification shall be made available along with the supporting field observation data indicating the reliability and accuracy of the instrument as well as the ruggedness. The Installation, commissioning and observations of Stress measuring devices in concrete and masonry dams may be done as per IS 14278 (1995).

The typical specification of commonly used *Stress meters* is appended in ***Annexure-B***

3.5.6 Strain measurement

Strain meters can be generally divided into two classes, namely (a) meters which can be used on surface and at an accessible location; and (b) meters that can be embedded into the body of the structure. Surface strain measuring devices are useful for superficial and short-term strain measurements. Embedded type instruments are useful for long-term strain measurements for finding out the structural behaviour of dams.

i) ***Meters which can be used on*** Surface ***and Accessible Locations***

The meters of the first class consist of a sensitive dial gauge and by some arrangement, the dial gauge measures the change in distance between two fixed points on the surface. The magnification of displacement between the two points is obtained by mechanical and optical means. Bonded wire, unbounded wire and semi conductor gauges are used for special applications only.

ii) Embedded type Meters

The only stable strain meters that have embedment applications are the unbonded resistance wire type and the vibrating wire type. The former works on the principle that the electrical resistance of the wire changes with the strain applied, while in the later the frequency of vibration of the wire changes with the strain applied. In the determination of the strains at a particular point in a massive structure, several choices of placing the instrument may be made, such as:

(a) One strain meter : This will provide strain history in one direction at the point without checking;

(b) Duplicate strain meters on one axis: This still provides information on only one axis but gives the reassurance of checking.

(c) Five strain meters: Four 45^0 apart in the plane of interest and one normal to the plane. Principal strains can thus be calculated from data furnished by a group of strain meters.

In addition to the set of strain meters indicated in (c) above, one ‘no stress’ strain meter is required to be installed by the side in conjunction with strain meter groups to determine the corrections to be applied on account of creep, autogenous growth and -thermal expansion of mass concrete. This is accomplished by embedding an ordinary strain meter in a typical mass concrete which is isolated from deformation due to loading but is responsive to the temperature, moisture and growth changes prevailing in the mass concrete of the structure.

In the case of masonry dams also, along with normal strain gauge meters, it is recommended that long gauge strain meters using unbonded resistance wire strain meters or joint meters or vibrating wire type long basis extensometers may be provided in a group side by side.

It is necessary to have at least five strain meter locations in a straight line from upstream face to downstream face and in one horizontal plane. The strain meters should be near the foundation level as stresses are maximum there.

a) Unbonded Resistance Type Normal Gauge

These instruments utilize the principle of change in electrical resistance of an elastic wire due to change in tension which is caused by strains in the surrounding concrete.

- The strain meter is in the form of a long cylinder with flanges on each end to anchor the ends of the meter to the surrounding concrete.
- White cotton cloth is wound around the cylindrical portion, which is corrugated in order to allow deformation. When the ends of the meter are pulled apart by expansion, the outer or expansion coil elongates and increases in tension and resistance. At the same time, inner or contraction coil decreases in tension and resistance as it shortens.
- Changes in the ratio of the resistance of the outer (expansion) coil to the inner (contraction) coils used as a sensitive measure of length change in the strain meter. The change in ratio of 0.01 percent normally indicates a change in length of about 4 millionth of centimetre per centimetre.
- Resistance ratio change are not affected by simultaneous changes due to temperature of the wires, since temperature change affects both coils by an equal amount.

b) Vibrating Wire Type

These instruments work on the principle that the frequency of the vibrating wire depends on the tension in the wire caused due to the strain in the surrounding concrete.

- This type of strain meter is also in the form of a long cylinder with flanges at each end to anchor the ends of the meter to the surrounding concrete.
- The pre-stressed vibrating wire is stretched between the two end flanges of the transducer in such a manner that the natural frequency of vibration of the wire is a function of the change in the distance between the flanges.
- The flanges, when embedded in a concrete structure, will follow the strain in the concrete; consequently, the square of the gauge wire frequency will be proportional to the strain in the concrete.
- A single gauge may be used or several gauges may be combined to form a variety of rosette configurations.

Stress meters and strain meters are generally installed side by side so that results of both the observations can be used together. Stress and strain meters may be installed at any location where development and observation of stress is of interest.

For further details regarding installation maintenance and observations of electrical strain measuring devices, IS 13232 (1992) may be referred.

The typical specification of commonly used "***Strain meter***" and "**no stress**" strain meter is appended in ***Annexure-B***

3.5.7 Pore pressure

3.5.7.1 *Concrete and Masonry dams*

For measuring the pore pressures in the body of concrete and masonry dams, the following device/instruments are used:

i) Pressure pipes; and
ii) Electrical pressure cells of two types, namely, electrical resistance type pore pressure cells and vibrating wire type pore pressure cells.

i) Pressure pipes

The pressure gradient acting along the direction of flow is a critical design parameter at the exit end of the structure. Design of the structure involves calculation of these pressures and gradients on the basis of certain assumptions. In these cases, therefore, actual observations of these pressures during actual operation become important. Therefore, it becomes essential to install pressure pipes on the structure itself with two objects in view;

- Firstly, to act as tell-tales watching the stability of the structure, and to predict any undesirable developments,

- Secondly, to investigate if the actual pressures at various points on the structure are in conformity with those assumed for purposes of design. A systematic record of their observations, apart from its scientific value, will be as necessary for the maintenance of structures as a record of usual subsurface soundings and probings.

ii) Electrical Resistance Type Pore Pressure Cell

Resistance type of pore pressure cell utilizes the two electrical principles, namely, changes in tension in elastic wires cause change in electrical resistance of the wires and changes in temperature of wires cause changes in electrical resistance of wires. This instrument has a solid steel diaphragm which is actuated by the pressure of the pore fluid which filters through a porous plug. The deflection of the diaphragm is measured by means of a strain meter unit. The space between the porous plug and the diaphragm is filled with petroleum jelly or water before use so that the response is almost instantaneous. The readings are taken by test set working on Wheatstone bridge principle and recorded on a suitable data form.

For further details, IS 8282-1 (1976): Code of practice for installation, maintenance and observations of pore pressure measuring devices in concrete and masonry dams, Part 1: Electrical resistance type cell may be referred.

iii) Vibrating Wire Type Pore Pressure Cell

The equipment consists of vibrating wire type pore pressure transducer, a signal cable and a frequency indicator/read out unit. The basic principle of the vibrating wire transducer is that the change in the natural frequency of stretched wire depends on the change of the tension in the wire. In this instrument, one end of the gauge wire is attached to the centre of circular membrane and the other end is secured to the top of the transducer housing. Fluid pressure applied to the membrane causes deflection of the membrane with consequent change in the tension of the wire and its resonant frequency. Thus, the frequency of the gauge wire is a measure of the deflection of the membrane, which is proportional to the pressure change.

Installation of pore pressure meters is a precise job and should be carried out with great care. In concrete and masonry dams, these meters may be installed normally at 10 to 15 m spacing along the width of the dam. The bottom row of pore pressure meters may be located either at the contact plane of foundation and concrete, or just above the foundation or in the foundation by drilling holes as may be required by the design. A second row may be installed at one-third or half the height of the dam.

For further details, IS 8282-2 (1996) Code of practice for Installation, Maintenance and Observations of Pore Pressure Measuring using Vibrating Wire Type Cell, may be referred.

The typical specification of commonly used *Pore Pressure measurement instrument* is appended in ***Annexure-B***

3.5.7.2 ***Embankment dams***

For measurement of pore water pressure in Embankment dams Piezometers are used. Commonly used pieozmeters are:

i) Porous Tube Piezometers
ii) Twin Tube Hydraulic *Piezometers*
iii) Electrical Piezometers
iv) Pneumatic Piezometers

i) Porous Tube Piezometers

The intake point of the Piezometer consists of a porous Carborundum/alundum tube of annular cross section. The bottom end of the porous tube is plugged with a suitable rubber stopper. The porous tube is set in a hole which is either drilled or jetted into the foundation/embankment to a predetermined elevation. The porous tube is surrounded by sand and has a riser pipe extended to the surface.

For further details, IS: 7356-1 "Code of Practice for installation, maintenance and observation of instruments for Pore Pressure Measurements in Earth Dams and Rockfill dams, Part 1: Porous tube Piezometers" may be referred.

ii) Twin Tube Hydraulic Piezometers

A Piezometer tip consists of a hollow cylindrical device which is machined or molded from a plastic (nylon or polypropylene) or any non-corrodible material. The Piezometer tubing is connected directly to the Piezometer tips by pipe through tube compression connectors. To prevent earth material and air from entering the Piezometer circuits, ceramic filter discs are installed in the open ends of the Piezometer tips by 'O' rings and stainless steel end plates. The two types of tips are (a) foundation type, and (b) embankment type.

For further details, IS: 7356-2 "Code of Practice for installation, maintenance and observation of instruments for Pore Pressure Measurements in Earth and Rockfill dams, Part 2: Twin Tube Hydraulic Piezometers" may be referred.

iii) Electrical Piezometers

Electrical Piezometer consists of a tip having a diaphragm, which is deflected by the pore water pressure against one face. The deflection of the diaphragm is measured by a suitable strain gauge which may be suitably calibrated to read pore water pressure. The strain gauge is either an electrical resistance (unbonded strain gauge) type or vibrating wire type. IS 12949 (1990) gives the details for installation, maintenance and observation of instruments for pore pressure measurements in earth dams and rockfill dams: Electrical pore pressure cells - vibratory wire type.

iv) Pneumatic Piezometers

In the pneumatic piezometers, the diaphragm deflection due to pore water pressure is balanced by a known air/gas pressure and recorded at the outside indicator end using pneumatic pressure gauges or pressure transducers.

3.5.8 Earth pressure

The Earth pressure cells are the usual instrument to measure earth pressure. They use a stiff diaphragm on which the earth pressure acts. The action is transmitted through an equalizing, confined, incompressible fluid (Mercury) on to a second pressure responsive element, the deflection of which is proportional to the earth pressure acting. The deflection is transformed into an electrical signal by a resistance wire (unbonded strain gauge) or vibrating wire strain gauge and transmitted through a cable embedded in the earthwork to a receiver unit on the surface. The measure of the electrical signal indirectly indicates the earth pressure by appropriate calibration.

The earth pressure cell may be designed to measure effective or total earth pressure or both. When it measures total earth pressures only, Piezometers should be placed by their side to measure pore pressure, which when deducted from the total earth pressure to give effective earth pressure. For observations of a retaining wall, when it is intended to note the change in the coefficient of earth pressure, clinometers should be fixed to the wall near the earth pressure cell to measure its tilting.

3.5.9 Measurement of Seismic Response and Dynamic Characteristic of Dams

Seismic measurements are made by installing Seismographs, Accelerograph and structural response recorders.

Strong Motion Accelerograph is generally provided on/near the base (in a recess provided in the foundation gallery) of the dam as well as at the top of the dam. It is preferable to provide them in one vertical plane section of the dam in at or near the deepest foundation levels. If the height of the dam exceeds 100 m, these may also be installed near the mid-height of the dam. Choice of installation locations need special consideration for capturing the general behaviour of dam monolith and avoidance of local influences of flexible appurtenant structural components like bridge piers and slabs.

The instruments located in the foundation gallery are meant for observing the input ground motion in the event of major earthquake. The instruments located at the top of the dam are expected to provide information about the response of the structure to the earthquake.

For further details, IS 4967: 1968 - Recommendations for seismic instrumentation for river valley projects, may be referred.

The typical specification of commonly used *Strong Motion Accelerograph* is appended in ***Annexure-B***

3.5.10 Other Measurements

3.5.10.1 Reservoir and Tail Water *Level*

Reservoir and tail water heads are among the principal loading to which a structure is subjected, the measurement of reservoir and tail water levels is essential for interpretation and realistic assessment of the structural behavior of the reservoir retaining structure.

Headwater and tail water levels are observed daily by means of gauges (scales) fixed on the dam, at locations conveniently visible. Where the hourly rate of variation of water level is rapid and this information is important for interpretation of observations, automatic continuous water level recorder should be fixed in shafts suitably located.

The typical specification of *Radar Type automatic Water Level Sensor* is appended in ***Annexure-B***

3.5.10.2 Rain Fall

Rainfall measurement is also a routine measurement as a part of hydrological observations. Rain gauges ordinary or self-recording type are normally installed at each dam site, however, use of advanced type rain gauges such as tipping bucket are not ruled out from use but are recommended being more accurate (see IS 5225 and IS 5235).

The typical specification of *Automatic Rain Gauge* is appended in ***Annexure-B***

3.5.10.3 Wave Height

Wave height can be measured by installing wave height recorder. The wave height information is important to assess the free-board of the dam.

A simple, portable, battery operated readout unit with a 4-digit LCD display should be used. Calibration data for each transducer should be provided when a simple readout unit to read frequency is used, for converting the frequency readings to relevant engineering units. Readout units with the facility to read the relevant engineering units directly on the display can be used in place of the frequency readout units.

Automatic wave height recorders are installed to measure wave heights. One type of this instrument provides an electric circuit, which is completed by lake water. The change in level of lake water due to wave, causes change in resistance/capacitance of the circuit which is automatically recorded by a recorder. Suitable calibration of change in resistance/capacitance in terms of change in water level gives the desired observation. The installation of such recorders will be required only for those reservoirs with long fetch, which is likely to experience high velocity winds.

3.5.10.4 Other Meteorological Measurements

Measurement of weather parameters can be achieved using an Automatic Weather Station requiring minimal human intervention. These instruments can record and store information on all the weather parameters at a chosen observation interval as per requirement. The data stored in local data storage can be retrieved at a later date using portable memory devices like pen drive/memory card. The data may also be transferred on real-time basis via a local link to a computer system or via telecommunications or satellite systems or even with GPRS/GSM mobile phone technology. They can be installed at far-flung locations without needing any observer making it a convenient choice. For details, SP: 61-1994 may be referred.

The typical specification of *Automatic Weather Station* is appended in ***Annexure-B***

3.5.10.5 Data about material properties

Properties of soils near the instruments should be determined while they are being installed. Grain size distribution, specific gravity and consistency limit tests should be carried out for soils near all types of instruments. Average field density and water content of soil layer in which the instrument is installed should also be noted. In case of instruments for observations of movements, consolidation tests should be done. When measurement of construction pore pressures is contemplated, laboratory construction pore pressure tests should be carried out. Permeability of compacted soils near piezometers should be determined. If assumptions made during stability analysis are to be verified, appropriate shear tests should be done. For earth pressure measurements, laboratory test should be run to determine the coefficient of earth pressure tit rest or according to anticipated stress paths.

A list of various IS codes available for dam instrumentation is attached in ***Annexure C***

CHAPTER- 4: INSTALLATION OF INSTRUMENTS

4.1 Installation of instruments

Detailed planning for installation should be co-ordinated among all parties involved, including the instrument supplier, owner's personnel and the construction contractor. Arrangements must be made to ensure that instruments arrive on time.

A co-operative working relationship with the construction contractor is essential, and the instrumentation field personnel should make a special effort to establish a co-operative relationship. The best way of establishing such a relationship for instrumentation personnel is to initiate thorough communication with all levels of the contractor's personnel several weeks or months before the start of installation work. The instrumentation personnel should meet with the contractor's engineers and supervisors to explain what will be done, why it must be done, and what will be required of the contractor. They should discuss access for installation and prepare sketches of detailed installation arrangements, linked to the contractor's actual method of construction, to forewarn the contractor on the impact of normal construction work. They should provide a list of materials that will be required for support work and be willing to tailor their installation plans to create minimum interference to the contractor's work.

In short, with proper and timely communication and coordination, among the various teams involved in planning, construction, procurement and installation; only the program of installation of instruments may succeed. Having established proper coordination, instrumentation personnel should maintain quality of work of installation, calibration and testing along with being responsive to the contractor and by working with the contractor to minimise any adverse incident.

4.2 Planning of instrumentation

The planning of instrumentation shall cover the following:

4.2.1 Contractual arrangements for installing instruments

Installation of instruments should preferably be under the control of the supplier to liaise with the contractor under overall control of the project authority or of instrumentation specialists selected by the Project Authority. Installation of instruments should be a team effort between support and specialist personnel.

4.2.2 Location of instruments

Location shall be shown on the contract plans, but the exact location of instruments shall usually be determined in the field, when geological details and construction procedures are defined more closely than during the design phase.

4.2.3 Detailed installation procedure

The instrument manufacturer's instruction manual will often be helpful when preparing detailed installation procedures, but many manuals provide insufficient guidelines. When site-specific constraints must be met, as is normally the case, the manufacturer cannot be expected to provide complete and definite procedures, and the user must plan detailed procedures to suit the geotechnical conditions of specific site . However, these procedures must be flexible enough to account for unexpected conditions that arise during installation, such as unexpected ground conditions or changes in the construction contractor's procedure or schedule.

4.2.4 Protection from damage

When embedded components that terminate at the ground surface are subject to damage by construction activities, special precaution must be taken. When vandalism is the over-riding issue, if possible terminal should be buried and made unobtrusive, since a strong protective box often increases a vandal to look for a stronger vandal. Hence, buried terminal can provide full proof method for protection from damage.

All vertical pipes should be provided with a cap to prevent the intrusion of debris. Where construction activities might damage the tops of vertical pipes or where vandals might block pipes by dropping stones, a removable plug should be installed at the appropriate depth.

4.2.5 Acceptance Tests

Acceptance tests shall always be performed to ensure, to the extent practicable, that installations have been completed satisfactorily.

4.2.6 Installation Schedule

Instrument should be installed as early as possible to provide vital initial reading for establishing reliable base conditions.

4.2.7 Installation Records

While installation of instruments, when installation personnel are required to enter data in blank spaces on a field form, they are more likely to follow the installation procedure with care. Further, these are required for both record purpose and whenever all or part of a system is modified, repaired or replaced and re-commissioning is required.

4.2.8 Installation Report

After completion of installation, an installation report will usually be required to provide a convenient summary of information needed by personnel responsible for data collection, processing, presentation and interpretation. The installation report shall contain at least the following information:

- Plans and sections sufficient to show instrument numbers and locations.
- Appropriate surface and sub-surface stratigraphic and geotechnical data.
- Descriptions of instruments and readout units, including manufacturer's literature and performance specifications (photographs are often helpful).
- details of calibration procedures.
- Details of installation procedures (photographs are often helpful)
- Initial readings.
- A copy of each installation record sheet.

The details of instruments are also provided in the Bureau of Indian Standards Codes on Instrumentation for River Valley Projects which are enlisted in ***Annexure - C***. In addition to this, the manual supplied by the manufacturers also contains the procedure for installing the instruments. Moreover, the installation procedure mainly depends upon actual site conditions in the field, hence, no details of installation of the instruments has been included in this chapter.

To facilitate the user, some typical sketches indicating the details for installation of the instruments as per various codes is appended as ***Annexure - E***

4.2.9 Cabling and Connection

- The term cable shall always include necessary type of connectors at both the ends for connecting between the two equipment. The connectors shall be properly anchored with the protective sheathing of the cable in such a way that the loads due to pulling and twisting shall be borne by the protective sheathing and the conductors shall not be subjected to any stress.

- The connectors shall be so fixed on the individual components of the system that the metal/plastic connector shall always transfer the load due to pulling and twisting directly to the protective body of the component and the internal interface cards/connections shall not be subjected to any load.

Wherever the cables are to be laid indoors and the length of the individual cable run exceeds 1 meter, the cable shall be housed in a protective conduit made of electrical supply grade conduit of appropriate diameter and the conduit shall be fixed with the wall at a height of not less than 1 meter above the floor surface. Whenever, the indoor cable is required to cross the floor, it shall be housed in a Galvanised Iron pipe of 12.5 mm internal diameter and the pipe shall be fixed to the floor with suitable protective covering for avoiding the tripping of the personnel using the area or disturbance to the pipe due to such movement.

Wherever, the cables are to run through open ground including the public road and pathways, the cable shall be armoured and shall be water ingress proof upto a static water pressure of 10 kg/cm^2.

All the joints made in the cable shall also meet the water proofing criteria. In addition, the cable shall be protected by housing the same in 12.5 mm. Galvanised Iron pipe embedded at a depth of not less than 1.5 meter below the ground surface with a warning brick on the same. A sketch of the cable layout with respect to the identifiable marks of the area shall be prepared and handed over to the purchaser for each such cable run on completion of the work of the cable laying operation.

The joints in the cable connecting between the sensor and remote terminal unit shall be avoided by measuring the appropriate length of the cable required and attaching the same in one piece. If the cable joints become necessary, prior permission of the purchaser shall be obtained before executing the same. The joint fabricated through a splicing and jointing kit shall be stronger than the parent cables.

The cables carrying data and electrical power shall be housed separately in different conduits separated by adequate distance to prevent leakage currents. The data cables shall also be laid out in such a way that the data integrity is not compromised due to mutual interference.

CHAPTER-5: INSTRUMENTATION DATA COLLECTION, PROCESSING, ANALYSIS AND PRESENTATION; ARCHIVAL AND MAINTENANCE OF DATA

5.1 Introduction

The purpose of dam instrumentation and monitoring program is to monitor the ongoing performance of the project so that conditions of concern can be quickly identified and properly addressed. These conditions of concern may indicate the need for maintenance, remedial action, or an imminent threat to the downstream population. Proper data collection, management, and analysis are vital for identifying and responding to these conditions so that the project can be operated safely.

An instrumentation programme is successful only when the instrumentation data is processed; result is evaluated and presented in a meaningful manner so that remedial action if needed can be initiated. The primary aim of data processing and presentation is to provide a rapid assessment of data in order to detect changes that require immediate attention. The secondary aim is to summarise and present the data in order to show trends and to compare observed behaviour with the predicted one so that necessary remedial action can be initiated. Personnel requirements for these tasks are frequently under estimated, resulting in accumulation of unprocessed data and failure to take appropriate action in time. The time required for data processing and presentation is usually similar to, and may even exceed, the time required to collect data.

5.2 Data Collection

Instrumentation data are usually recorded from the instrument observation by project personnel on a data sheet/format. The data is then transmitted to the agency responsible for processing and interpretation. These instruments are read at a specific frequency which is established.

Various methods and formats of data collection are being used by project owners and operators. Most importantly, the data collected must be what is required to meet the monitoring objectives. This means both selecting the correct parameters to monitor and defining the frequency of data collection needed. For example, if the parameter that is being monitored can change rapidly, then very frequent readings and possibly real-time notification of a change may be needed. On the other hand, collecting frequent data for a parameter that is expected to change slowly may result in unnecessary data which can become a distraction.

Data can be collected using manual measurements that are made by project personnel. Alternatively, data can be collected using electronic equipment that stores the data until it is downloaded or automatically transmits the data to a remote location using radio, telephone, satellite, or an internet connection. The best method for data collection will depend on many factors including types and quantity of data to be collected, the reading schedule and frequency, site access limitations, availability of electrical power, availability and qualifications of monitoring personnel, and other factors. The following is a brief discussion of the three general types of data collection currently used for collecting dam safety monitoring data.

5.2.1 Manual Data Collection

As data is collected manually in the field, it may be entered into a field survey book, paper forms, a handheld device, or a tablet PC. Data must be entered correctly and complementary data such as date and time of the reading, reservoir/river and tail water levels, ambient temperature, precipitation, and other relevant site conditions should be noted. Manual collection methods can include the use of weighted tapes, scales, calipers, survey rods, and other measurement devices which may be read manually.

The measurements might also be made using electronic sensors with readout devices. These readout devices sometimes allow for digital storage of the readings which can be later downloaded to a computer in the office. Digital photographs are collected to assist in documenting the current conditions. Once the data have been collected and transported into the office, the data may be graphed or tabulated for analysis by hand or entered into a computer for analysis and presentation. In addition, visual observations made during the data collection must be stored in a manner that allows for future reference and retrieval.

The data collection process should include procedures to verify that the reading has been performed correctly, and should also include a comparison with previous readings or limits to verify that the recorded readings are within the expected historical range of the instruments. If readings do not fall within the expected performance range, procedures should be in place to address the apparently anomalous readings promptly; this may include re-reading the instrument to verify the accuracy of the anomalous data, checking the calibration of any electrical or mechanical readout devices or sensors, increasing the frequency of readings, and other measures judged to be appropriate. Few sample formats for manual data collection as per IS code and field practice for status of instrumentation are attached in ***Annexure D***

5.2.2 Stand-Alone Data loggers

Sometimes, readings are required to be collected at short time intervals, e.g. every 15 minutes, hourly or daily to meet monitoring objectives. These readings can be very helpful in developing an understanding of how the dam responds to changing loading conditions such as reservoir level, rainfall, and air temperature, for example. Readings from multiple instruments can be collected simultaneously so that different parameters can be directly compared. This can also be accomplished with manual readings, but depending on the size of the project, number of instruments, location of instruments, and frequency of readings, it is generally too labor intensive if readings are needed at an interval of more than once a day.

When frequent readings are required, standalone data loggers can be an effective data collection method. Stand alone data loggers can also be used to capture data when an event of interest occurs. For example, the data logger can be configured to monitor a water level or flow rate sensor and collect data at short time intervals if the reading exceeds a threshold value. Data loggers may also be a good alternative to manual readings for remote sites or for areas of difficult access, such as a dam gallery.

There are many different types of standalone data loggers and a number of manufacturers make units that are battery- or solar-powered and environmentally hardened for direct field deployment. These units can be configured using a computer or handheld device and then left in the field for unattended data collection. The data is then retrieved using the computer or handheld device by personnel who periodically visit the site. Visual observations and manual readings on other less frequently read instruments are typically performed during these periodic site visits. Site visits for downloading data should be performed frequently because data could be lost if a datalogger malfunctions. Also, regular visual observations should continue to be performed even if data is being collected frequently, as visual observations can often identify developing problems before an instrument registers a response.

Data loggers can be configured to read single instruments or they can be used to read a number of sensors. Once data has been downloaded from the data logger, the data then must be uploaded to a computer for evaluation. This should be done promptly following collection of the data. Similar to the manual readings, a verification procedure should be in place to make sure that accurate readings are recorded. For example, if irregular readings are noted upon uploading the data, these should be immediately investigated, explained, and/or corrected. Also, periodic manual readings should be taken to verify the digital readings.

5.2.3 Real-time Monitoring Networks

If both frequent unattended data collection and real-time display or notifications are required, then an automated data acquisition system (ADAS) may be the best option. Automated systems can also save labor and reduce the time for data evaluation by providing automated data retrieval from a remote location. The data is typically retrieved from the site periodically and automatically loaded into a database for presentation to the end user. Using programmable ADAS equipment, data can be processed into engineering units, evaluated for alarm conditions, and displayed in real-time to operations and dam safety personnel. These displays can be customized to present the monitoring results in the format needed to make decisions. For operations personnel this may mean simple displays that show normal or alarm conditions.

The interface for the dam safety personnel usually warrants a more comprehensive presentation for evaluation of short term trends, correlation relationships, alarm thresholds, statistical parameters, and geographic relationships. Although ADAS provides remote monitoring of the project, regular site visits are still required to perform the scheduled visual observations and system maintenance tasks. Many projects that utilize an ADAS for some instruments also have other instruments that require less frequent readings and are read manually. The typical specifications of Data Acquisition Systems (DAS) & its Accessories are given in ***Annexure B.***

There are two general system architectures that are used to automate the collection of performance monitoring data on dams: host-driven systems, and node-driven systems. The host-driven architecture consists of a central intelligent host (master) device and remote units (slaves) that are pooled by the master unit to collect the instrument readings. Because the intelligence is primarily in the host device, the system performance relies heavily on maintaining stable uninterrupted communications. Examples of host architectures are supervisory control and data acquisition (SCADA) systems and PC- based systems.

The node-driven architecture, in contrast, puts the intelligence at each node in the network. A node would be a location on the dam site that monitors a single instrument or a group of instruments, but is physically separated from the other nodes. Each node is capable of standalone operation and can be programmed to collect data and make alarm notification decisions on its own. The nodes may be configured to allow for two-way communications with each other so that information can be readily shared between the units. This information may be measured with parameters used in calculations such as a barometric pressure correction, or it may be instructions to increase the rate of data logging based on a certain reservoir level condition or the occurrence of strong shaking from an earthquake.

Communications between the nodes can be accomplished by a wide variety of wireless and hardwire methods. The best method will depend on site conditions, communication services available, and the real-time monitoring and notification needs of the project. The node-driven architecture is more commonly used for dam safety monitoring because the instrumentation tends to be widely distributed around the project site and in locations where power is not readily available. Low power operation is possible with the node driven systems because communication activity can be minimized while still maintaining the real-time functionality of the system. If a node detects an alarm condition, it can immediately communicate with the other nodes, but under normal conditions, communications are kept to a minimum. A properly designed node-driven system can also provide improved reliability. In the event of the loss of communications or equipment damage in the network, the other nodes will continue to function independently. For critical systems, it is also desirable to have multiple communication paths that can be utilized.

The primary advantage of an ADAS is to allow for the near real-time collection and reduction of the instrumentation data so that dam operators and dam safety personnel can rapidly evaluate the conditions at the dam. A properly designed ADAS provides real-time remote notification of a significant change in the performance or conditions at the dam 24 hours a day, 7 days a week.

5.3 Advantages and Disadvantages of various method of data collection

Table 5-1 summarizes some of the advantages and disadvantages of the three data collection methods described above. The objective in designing a monitoring program is to use the best tools for the intended purpose. Many dam projects use a combination of the data collection methods depending upon the monitoring needs for the parameters that are being measured.

Table 5-1 Summary of Data Collection Methods, Advantages and Disadvantages

Data Collection Method	Advantages	Disadvantages
Manual Readings	• Generally simple to perform and do not require high level of expertise • Personnel are already on site for regular visual observations • Data quality can be evaluated as it is collected	• Labor intensive for data collection and reduction • Not practical to collect frequent data • Potential for errors in transposing data from field sheets into data management/ presentation tools • May be impractical for remote sites where personnel are not frequently on site
Standalone Data loggers	• Frequent and eventdriven data collection • Consistent data collection and electronic data handling • Equipment is fairly inexpensive and simple to set up	• Requires some expertise to configure dataloggers • Data quality cannot be evaluated until it is collected from the field • Potential for lightning strikes • Power source needs to be considered
Real-time Monitoring Networks	• Frequent and event-driven data collection • Consistent data collection and electronic data handling • Real-time display and notification (24/7) • Reduces labor effort for data collection and processing • Can remotely change the monitoring frequencies and data collection configurations as needed • Allows for rapid evaluation of monitoring results	• Automation may encourage complacency if overall monitoring program is not well defined or understood • Requires a higher level of expertise to install and maintain • Higher cost of installation and periodic maintenance • The importance of frequent routine visual inspections may be overlooked or discounted somewhat due to the real-time presentation of automated instrument readings • Potential for lightning strikes • Power source needs to be considered

Source:Guidelines for Instrumentation of Large Dams, Central Water Commission, January 2018

5.4 Frequency of Data Acquisition

Establishing frequency of data acquisition is one of the most important aspects of instrumentation programme and eventually reflects in the analysis of the instrumentation data. Table 5-2 presents the suggested frequencies of data acquisition for different stages of a dam project as listed below :

- During construction;
- During initial filling of reservoir;
- During period of operation (1st year, 2nd and regular)

The frequencies are suggested in the table 5-2 which are only guidelines for an instrumentation programme and should be intensified, if required, in case of the following circumstances, which could possibly create distress in dams calling for immediate remedial actions :

- Rapid rate of filling of the reservoir.
- A flood surpassing the maximum reservoir elevation.

- A rapid draw down of the reservoir (in case of embankment dams).
- Occurrence of seismic event felt or recorded other than isolated micro-earthquake activity.
- During the course of consistent abnormal behaviour of a set of instruments.
- Any other event justifying more frequent data acquisition.

Table 5-2 Suggested Frequency[a,b] of Readings for Specified Instruments

Type of instrument	During Construction		During initial filling	During Period of Operation		
	Construction	Shutdown		Year 1	Years 2 to 3	Regular
Vibrating wire Piezometers	W	M	W	BiW	M	M
Hydrostatic uplift pressure pipes	W	M	W	W	BiW	M
Porous-tube Piezometers	M	M	W	W	M	M
Slotted-pipe Piezometers	M	M	W	W	M	M
Observation wells	W	M	W	W	BiW	M
Seepage measurement (weirs and flumes)	W	M	W	W	M	M
Visual seepage monitoring	W	W	W	W	F	M
Resistance temperature meters	W	M	W	W	M	M
Thermocouples	D	M	W	W	M	M
Carlson strain meters	W	W	W	BiW	M	M
Joint meters	W	W	W	BiW	M	M
Stress meters	W	M	W	BiW	M	M
Reinforcement meters	W	M	M	M	M	M
Penstock meters	W	M	M	M	M	M
Deflectometers	W	M	W	W	M	M
Vibrating wire strain gauge	W	M	M	M	M	**M**
Vibrating-wire total pressure cell	W	M	M	M	M	M
Load cell	W	M	W	BiW	M	M
Pore pressure meters	W	W	W	BiW		M
Foundation deformation meters	W	W	W	BiW	M	M
Flat jacks	D	W	W	BiW	M	M
Tape gauges (tunnel)	W	W	W/BiW	BiW	M	M
Whitmore gauges, Avongard crack	W	M	W	W	M	M

Type of instrument	During Construction		During initial filling	During Period of Operation		
	Construction	Shutdown		Year 1	Years 2 to 3	Regular
meter						
Wire gauges	W	M	W/M	W/M	M	M/Q
Abutment deformation gauges	W	M	W	W	M	M
Dial gauges, differential buttress gauges	W	M	W	W	M	M
Plumblines	D	W	D	W	BiW	M
Inclinometer	W	W	W	W	BiW	M
Collimation	Every two days for a month	M	W	BiW	M	M
Embankment settlement points	-- [c]	--	M	BiM	Q	SA
Level points	M	Q	M	M/Y	BM/Q	BM
Multipoint extensometers	W	M	W	M	M	Q/SA
Triangulation			M	M	Q	SA
Trilateration (EDM)	--	--	BiW/M	M	Q	Q/A
Reservoir slide monitoring systems	--	--	M	M	M	Q
Power plant movement	--	--	M/W	M	M	M/Q
Rock movement	W	M	W	M	M	M

[a]These are suggested minimums. However, anomalies or unusual occurrences, such as earthquakes or floods, will require additional readings. [b]D = daily, W = weekly, BiW = bi-weekly, M = monthly, Q = quarterly, SA = semiannually, A = annually. [c]Not applicable.

Source: Guidelines for Instrumentation of Large Dams, Central Water Commission, January 2018

5.5 Accuracy of Data

It is preferable to have no data than to have wrong or poor data, which may even lead the reviewer to arrive at improper interpretation and thereby resorting to inappropriate actions. From this, it implies that data accuracy is very essential and elimination of errors, if any, is the responsibility of every individual dealing with data.

An instrumentation reading is useful only if the correct calibration is known. Zero shifts and scale span changes of transducers can occur because of normal wear and tear, misuse, creep, moisture ingress and corrosion. If these changes are not accounted for, the entire monitoring program can become worthless. To maximize their effectiveness, all instruments must be calibrated and maintained properly.

5.6 Instrument Calibration

Calibration consists of applying known pressures, loads, displacements, or temperatures to an instrument, under controlled environmental conditions and measuring the response.

Instrument calibrations are generally required at three stages : prior to shipment of instruments to the user, when instruments are first received by the user and during service life of instruments

5.7 Instrument Maintenance

Regular maintenance required during service life is usually performed by personnel responsible for data collection and shall be under the direct control of the project authority or instrument specialists selected by the project authority. Personnel responsible for data collection shall always be on the lookout for damage, potential for damage and deterioration or malfunction and should initiate repair or replacement without delay. Detailed maintenance requirements vary with each instrument and should be stated in the manufacturer's manual. Appropriate spare parts should be ordered when instruments are procured to replace accessible malfunctioning components during service life. Provision should also be made for spare or standby readout units for use in case of malfunction. Maintenance personnel should ensure that adequate spare parts and readout units are in hand or readily available.

Particularly, the maintenance of the following be taken cautiously:

- Readout Units
- Field Terminals
- Embedded components

5.8 Observation Period

There appears to be an impression in some quarters that observation of instrumentation could be discontinued after some years of normal / trouble-free performance of the dam. However, monitoring of the performance of the dam is important throughout its life and it becomes more vital when the dam becomes old. In fact, older the dam, more are the anticipated problems.

It is, therefore, pertinent that data from different instruments installed in a dam to monitor its behaviour is continued to be observed throughout the life of the dam, however, the frequency of observation may be reduced after certain number of trouble-free and satisfactory operation of the dam.

5.9 Data Transmittal

Instrumentation data acquired by the project personnel is transmitted to the agency responsible for processing and analysing data. The data transmittal can be accomplished in the following four ways:-

- By mail, which is the most commonly used form of data transmittal.
- By computer link.
- By telephone and
- By satellite link (for automated instrumentation).

Timelines in transmittal of the data from the field to the agency charged with its analysis is of utmost importance.

5.10 Processing of Instrumentation Data

Once instrumentation data has been collected, evaluation of the information collected is required. Calibration information, baseline information, and instrument locations are all necessary in order to process data.

Data processing may be carried out for the following stages of the dam:

* Construction.
* Test Filling.

* Initial Filling.
* First Year of operation of the project.
* Subsequent years of operation, which could normally be annual.

Data processing involves compilation of data transmitted by the project personal and generation of plots. The plots can be generated both manually and on computer. If there is any missing data during the period, the project authority should be reminded immediately.

For instance, vertical movement readings such as crest settlement data must be processed by evaluating the relative change in vertical elevation between consecutive surveys as well as the change from initial surveys. Additional processing of vertical movement readings can include developing plots of the data to evaluate trends over time or with respect to other references. Likewise, readings from Piezometers must be processed to determine the elevation of the water in the instrument using the raw reading of the depth to water measured and the surveyed ground and top of Piezometer elevations. Other reference information such as the installed location of instruments, materials in which the instruments are installed, etc. are important for interpreting the data and evaluating how the dam is performing. Some of the processing can be automated depending on the method of data collection and management used. Spreadsheets can be developed to automatically process raw data as the information is entered. Likewise, databases and other available software can be programmed to automatically process data as raw data is input and/or uploaded. As with manual processing, automatic processing of data relies upon well documented reference information, calibration data, and instrumentation details. Therefore, managing and archiving the reference information is equally as important as the management and archiving of raw data.

5.11 Screening of Data

Data are usually screened in two steps, prior to data calculation and plotting. The first data screening step is laid in the field itself by the data collection personnel. The second data screening step is made in the office by data processing personnel and entails scrutinising the field data, making any obvious errors on field data records and reviewing the evaluation of data correctness made earlier in the field. When obvious errors are found, repeat readings will usually be required. Additional screening is possible by evaluating plots of raw data or computer generated tabulations designed specifically for screening purposes.

5.12 Calculation

Data that appears false are discarded first and remaining raw readings are transcribed from field data records to calculation sheets for conversion to engineering units. Calculation sheets should be made specially for each project and individual instrument to record project name, instrument number, date and time of readings, initials of persons making and checking calculation.

5.13 Plots of Data

After calculations have been made, plotting of the data should be done so that interpretation of data is not delayed. These plots will be used by data collection and processing personnel to assist in an assessment of data quality and to show data trends and will be used as base material for data interpretation, and these will be updated whenever new data are collected. Generally, the routine plots of data versus time are adequate for predicting future trends.

Few sample plots are placed at ***Annexure- F*** for reference.

5.14 General Guidelines on Interpretation of Data

There should be real sense of purpose for installing an instrument, monitoring programme, the method of data interpretation etc. Without a purpose, there may not be a significant interpretation. The essence of subsequent data interpretation is to co-relate the instrument readings with other factors and to study the deviation of the readings from the predicted behaviour. By its nature, interpretation of data is a people intensive activity, and no technique has yet been developed for automatic interpretation of data.

Interpretation is a task for experienced geotechnical engineers. They should be familiar with the monitoring programme, project construction period, details of instrumentation installation, data collection, processing and presenting. They should have computational and analytical skills and should be capable of exercising engineering judgement.

Interpretation and re-interpretation of data is on-going process and is dependent on factors specific to each instrument and project. Initial interpretation is of tentative in nature and depends upon collection of further data. Interpretation may change as a clearer understanding of real behaviour is developed. Assessment of performance of an individual instrument often requires a study of data for a significant time period.

When faced with data that on first sight do not appear to be reasonable, there is a temptation to reject the data as false. However, such data may be real and may in fact carry an important message. Details recorded on installation record sheet are often helpful when evaluating the rejected data because difficulties encountered during installation may be used for ascertaining cause of abnormal data.

After each set of data has been interpreted, conclusions must be reported in the form of a monitoring report and submitted to the personnel responsible for implementation of remedial measures if any suggested therein.

5.15 Cause and effect relationship for data interpretation:

Certain relationships normally exist among various factors that act upon dams. These relationships are outlined below in **Table 5-3.**

Table 5-3: Cause and Effect relationship for data interpretation

Interrelated Physical Factors	How Their Relationships Affect Data interpretation
Water Pressure/ Reservoir And Tail-water Levels/ Precipitation	• Water pressure in or under an embankment, or under a concrete dam, is related to reservoir and tail-water levels. • Water pressure in the abutments of a dam is related to reservoir and tail-water levels. • Water pressure in the slopes of a dam is directly related to reservoir level. • Precipitation and local ground water may influence water pressure in or under embankments, under concrete dams, in dam abutments, and in the slopes of a dam.
Water Pressure movement	• As water pressure increases within an embankment, or in a dam's foundation or abutments, the effective shear strength available to resist movement is reduced. If this shear strength is reduced to less than driving forces, movement will occur.
Water Pressure / Seepage / Reservoir Level / Precipitation	• Seepage normally is directly related to the reservoir level. • Precipitation often results in a temporary increase in the seepage flow. • Decreasing seepage flow and increasing water pressure under the dam or in its abutments indicate that the drainage or exit control systems are losing their effectiveness. • Decreasing seepage flows and decreasing water pressure under the dam or in its abutments indicate that the infiltration of reservoir water into the foundation or abutments is decreasing (possibly due to siltation of the reservoir basin).

Interrelated Physical Factors	How Their Relationships Affect Data interpretation
Movement/Reservoir Level	• Normally, as the reservoir level increases, a concrete dam will deflect in the downstream direction. • Reservoir-level increases normally will not cause embankment dams to deflect significantly. • For very high earth and rockfill embankment dams, measured movements may be influenced by reservoir-induced settlement. • An acceptable value of lateral deflection after filling is difficult to predict for any size of embankment dam • The key consideration for an embankment dam is that vertical settlement or lateral deflection of the crest should decrease in rate over time for a constant loading condition. A sudden or even gradual increase in the rate of vertical or lateral movement should be cause for further evaluation • The predicted Piezometer levels will obviously vary with size and type of dam, height of reservoir, etc., and acceptable ranges cannot be quantified except on an individual basis.
Movement/Temperature	• Concrete expands as temperature increases, and contracts as temperature decreases. • In locations with large differences between summer and winter temperatures, concrete monoliths in a dam will move, causing joints and cracks to open in the winter and close in the summer. • In the summer, as the temperature of the downstream face of a dam increases, the concrete near the downstream face will expand. Meanwhile, because the reservoir keeps the upstream face at a more constant temperature, there is little or no expansion of the concrete near the upstream face. This differential expansion of concrete may cause the top of the dam to move or rotate slightly upstream.
Seepage/Temperature	• The seepage or leakage through the cracks and joints of a concrete dam is inversely related to the temperature of the air/concrete/water. • For dams founded on fractured rock that experience seasonal changes in water temperature, there will often be an increase in flow from foundation drains during the winter.
Seepage/ Water Pressure/ Turbidity /Solutioning	• Turbid flow or increasing turbidity levels may indicate changes in seepage flows and water pressure. • Any sudden change in water pressure should be followed by seepage flow inspections. • A steady increase in seepage, with no increase in turbidity, indicates that seepage should be tested for the presence of dissolved solids.
Seismic Activity/Seepage Movement/Water Pressure	• Ground motion can cause a dam to move or deform, resulting in damage and/or structural instability and failure. Such movement can also damage seepage control features. • Seepage rate increases, increasing turbidity, or a large increase in water pressure could all indicate that damage has occurred to the structure. • Leakage/ Seepage is sensitive to earthquakes and is an important factor affecting the stability of dam body and its foundation • Case studies show that leakage/seepage and pore

Interrelated Physical Factors	How Their Relationships Affect Data interpretation
	pressures often changes as a result of ground shaking. Usually they increase after an earthquake • In most cases, the increase is only temporary and will decrease or become stable over time and it may last from several days to a few years until a stable condition is reached
Construction Activity	• During construction or rehabilitation activities, high water pressures, sudden changes in water pressure or seepage, and/or unexpected movements would indicate the possible development of unsafe conditions.

Source:Guidelines for Instrumentation of Large Dams, Central Water Commission, January 2018

5.16 Data Archival and Data maintenance

The acquired data is priceless, so the maintenance of data is an important activity of a dam safety program. The specific combination of factors which actually produced the instantaneous values can never be replicated. Hence, efficient archiving of collected data on a permanent basis is the prime need and it is vital to provide adequate resources for this activity.

A complete record or history of the investigation, design, construction, operation, maintenance, surveillance, periodic inspection, modifications, repair, and remedial work should be established and maintained so that relevant data relating to the dam is preserved and readily available for reference. This documentation should commence with the initial site investigation for the dam and continue through the life of the structure.

Typical records essential to maintain for an instrumentation program include design memoranda, instrumentation data, installation and maintenance records for instrumentation, significant event records, reports of significant remediation to the dam, and data evaluation reports. Of critical importance is the maintenance of historic information which, as staff and responsibilities change, must be maintained and included as part of regular training of incoming or rotating staff. Information that should be maintained includes:

- General information such as drawings, date(s) of installation; initial measurements and testing; manufacturer's calibration data; borehole logs; model number and manufacturer; wiring schematics, etc.

- Instrument maintenance records including routine maintenance activities; calibrations of instruments; cleaning of foundation drains; replaced readouts; removal of vegetation; cleaning of approach channels of weirs; outages, reservoir drawdowns, major maintenance; installation of drains, flushing of pieozmeters, and redirecting flow, etc. These are often sources of changes in recorded data. Maintenance records also provide documentation of schedules, reasons for repair (such as damage from vandalism or construction), and information for future maintenance and may also provide support to explain abrupt changes in readings.

- Significant project event records such as records of floods, earthquakes, major construction, and remediation must be maintained. These will provide information on the performance of the project under these loads and can provide critical empirical information to help with calibration of dam safety analyses that are intended to evaluate and prepare for future extreme events.

- Data evaluation reports, or performance reports, are the tangible product of instrumentation programs. As such, managers must ensure their maintenance and availability to all personnel responsible for some aspect of the dam safety and performance of the project

CHAPTER - 6: RECOMMENDATIONS

6.1 Manpower

It has been observed that there is a considerable amount of the personnel turn around during the construction of the dam. The personnel in charge of instrumentation are also part of the overall process. It is therefore, evidenced quite frequently that the original set of personnel who received training and instructions for installation and care of instruments are no more available when the actual installation and operation is to be performed.

These areas needed attention from the point of view of overall personnel turn around and large time spans involved in the construction of the dams. One of the key issues involves the passage of relevant information from one group to the succeeding group of the executing personnel. Information like calibration data and instrument constants required for data processing are also determined at the time of installation only and they need to be passed along a long period of time for the future analysis and studies. The preservation and security of such data can be best handled by the modern computer based tools and storage media.

The project authorities should designate a group of Engineers as in-charge of "Observation and Post Installation Maintenance of Instrumentation Programme"

6.2 Training

Training to the designated project personnel from the first step of installation to the interpretation of data along with preventive maintenance of all instruments and associated requirements will have to be imparted invariably prior to the implementation of the proposal for successful instrumentation. Project personnel should be trained on installation at least of one instrument of each type out of the various types of instruments specified to be installed and shall be made fully conversant by a presentation highlighting the do's and don'ts.

The contractor /supplier /installation agency shall also make arrangements for the complete training of a group of personnel likely to be engaged in the installation of the instruments, carrying out observations on them and processing the readings for obtaining parameters of interest like strains, stresses, pressures and temperatures etc. The project personnel shall also be trained in preliminary trouble shooting of readout sets and their preventive maintenance. Site personnel shall be involved in the storage, unpacking, protection, final calibration of the instruments and installation of the same at site.

6.3 Seismic Instrumentation

For many large dams, the seriousness of earthquake hazards and overall importance of the project will be such that a very extensive instrumentation program under the direction of expert consultants will normally be involved. Such projects go far beyond the scope of the present document, which aims only at establishing certain minimum standards which can be recommended only for all major dams at a high level of justification. Smaller dams, however, may have a high disaster potential. This suggests that the local seismograph network could be limited to high dams, but the strong motion instrumentation should be included for lower dams as well if danger to population is involved.

6.4 Documentation

In order to judge the utility and benefits of instrumentation the complete record should be well documented.

The event causing damage to structure should invariably documented and made available to the concerned.

6.5 Inspection

Diligent visual inspection and instrumentation monitoring are an integral part of dam safety. Instrumentation monitoring provides necessary information on the structural behaviour of the structure and may detect developments of any undesirable condition. Any early detection improves the chances of taking remedial measures in time. A well planned instrumentation programme targets the potential failure mode and gives an indication of changing deteriorating performances or the onset of distress. Any minor incident related to dam instrumentation, whether it is of no significance momentarily, should be recorded for future reference.

Following guidelines provides the principles that the Project Authorities need to follow to ensure the safety of their dams. These guidelines are based on international practices:

- Initial reading of all the instruments should be made and formalised as base line data**.**

- Instrumentation should be monitored, evaluated and maintained and the data should be compared with the previous readings and with the expected design assumptions.

- The mode and methodology of observing the instruments should be described i.e. manual or automated. If automated, the system should be described including modem telephone numbers and if manual, there should be documentation of methodology, maintenance and storage of reading equipments.

- Water level monitoring equipments must be located in an area which is free from local drawdown effects.

- Adequate surface drainage should be provided on the downstream face of the dam.

- Assessment of seepage / drainage from foundation may include:

    - Determining whether the quantities of seepage are acceptable in considerations with geological conditions.
    - Identifying any evidence of leakage along weathered seams, open joints etc.
    - Identifying whether the drainage system is functioning.
    - Determine whether the grout curtain is performing satisfactorily.
    - Water quality should be monitored for any chemical reaction of pore water.

- Carryout Pre and post inspection of embankment to make sure that:

  -Downstream slope drainage arrangements works satisfactorily.
  -Drains are properly maintained and free from vegetation growth and debris.

-Seepage measuring points are easily accessible and free from vegetation growth and debris.
-Measuring point are properly located, constructed and maintained.
-Seepage measurement is done after cleaning the edges of the weirs.

- All the instruments installed should be readily accessible, properly lighted, ventilated, and adequately protected from the possibilities of damage.

- Post the observation on a recording documents and obtain test observation from the responsible person with his initials.

- Keep the sufficient stock of spares, gauges, stationary at the site.

- Read all the equipments at the proper interval and record anomalies if any.

- Provision may be made for standby power supply during inspection of the instrumentation gallery by the higher officers and ensure that the gallery is not flooded.

***

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7. Guidelines for Instrumentation of Large Dam, Central Water Commission, January 2018
8. Technical Specifications of Hydro-meteorological, Geodetic, Geotechnical and Seismic Instruments, Central Water Commission, January 2018

Annexure-A

Parameters required to monitor the performance of Gravity Dams and various instruments for same are given below:

Parameters	Suitable Instruments
1. Uplift Pressure	I Vibrating wire Piezometer II Unbonded electric resistance Piezometers III Multipoint Piezometer with packers. IV Multipoint Piezometer surrounded with grout V Multipoint push in Piezometers
2. Seepage	I Weirs i) V-Notch ii) Rectangular weir II Flumes
3. Temperature	I Resistance Temperature meter II Temperature meter Vibrating Wire III Thermisters
4. Displacement	I Extensometer II Whitemore gauges Optical III Crack monitoring IV Calipers V Micrometers VI Dial gauges
5. Stress	I Gloetzi cell II Carison load cell III Vibrating wire stress IV Flat jacks
6. Strain	I Resistance Type strain meter II Vibrating wire strain meter III Weldable Strain meter IV No stress-strain meter
7. Pore Pressure	I. Open System Type (i) Porous tube Piezometers (ii) Slotted pipe Piezometers II Closed System Type (i) Hydraulic twin tube Piezometers (ii) Electric Piezometers a). Vibrating wire strain gauge Piezometer b) Resistance strain gauge Piezometer III Total pressure cells
8. Seismic	Seismographs i) Strong Motion Accelerograph ii) Structural Response Recorders
9. Joint	Joint meters
10. Deformation	I Multipoint borehole extensometer II Foundation deformation gauges III Tunnel type gauges

The Parameters required to monitor the Performance of Earth/ Rockfill Dams and various Instruments for same are given below:

Parameters	Suitable Instruments
1. Water Pressure	I. Open System Type (i) Porous tube Piezometers (ii) Slotted pipe Piezometers II. Closed System Type (i) Hydraulic twin tube Piezometers (ii) Pneumatic Piezometers (iii) Electric Piezometers a). Vibrating wire strain gauge Piezometer b). Resistance strain gauge Piezometer III. Total pressure cells
2. Seepage	I. Bucket and stop watch II. Weirs (i) V-notch (ii) Cipolletti (iii) Rectangular III. Flumes (i) Trapezoidal (ii) Parshall IV. Flow meters V. Velocity meters (i) Based on pilot tube principle (ii) Propeller type device (iii) Acoustic flow meter (iv) Electromagnetic current indicator VI. Water quality meter VII. Turbidity meter VIII. Infrared aerial photography IX. Geophysical seepage monitoring (I) Thermotic surveys (ii) Self Potential surveys X. Resistivity surveys
3.Deformation i) Internal movement	 I Cross arm II Foundation base plates III Pneumatic settlement centre IV Vibrating wire settlement sensor V Inclinometer VI Multi-point extensometer VII Shear strips VIII Radio-sonde systems

Parameters	Suitable Instruments
ii). Surface movement	I Tiltmeter II Theodolite III Electronic Distance Meter IV Crack meters
4. Vibration measurements	I Geophones II Strong Motion Accelerograph III Seismographs
5. Rainfall	ORRG / SRRGS

Annexure- B

Table B-1 Typical Specifications of Uplift Pressure Measuring Instrument

The Instrument should conform to the following technical specifications:

Feature		Value
Site Conditions	Operating temperature range	-20 to + 60°C
	Operating humidity	5 to 100%
	Altitude	0 to 2500 metres
Sensor	Type	Mechanical, Vibrating wire
	Operating range	10 kg/cm^2
	Over range	1.5 x Range
	Over range effect	±0.1% F. S.
	Resolution	0.025% F. S
	Accuracy	±0.1% F. S.
	Temperature compensation	Inbuilt
	Linearity	--
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
General Features	Enclosure	Stainless steel, IP 68
	Accessories	Sensor mounting support, cables and other accessories as required
	Protection	IP 68 or NEMA-4
	Manuals	Full documentation and maintenance manual in English

Table B-2: Typical Specifications of V-Notch Weir for Flow Measurement:

The equipment offered should conform to the following technical specifications:

Feature	Value
Site Conditions	
Operating temperature range	-20 to + 60°C
Operating humidity	5 to 100%
Altitude	0 to 2500 metres

MEASURING METHOD:

(a) Electronic type	Vibrating wire seepage measurement system shall be designed to measure a flow rate of around 0-100 litre/second. The seepage water would be collected in a concrete reservoir and made to flow over a V notch weir. The rate of seepage water flow is calculated from the level of water over the weir. The system to consist of a thin stainless steel plate 90^o V-notch weir, a submersible cylinder and a vibrating wire load cell. The submersible cylinder to be permanently suspended from low capacity vibrating wire load cell mounted on a stilling well or a gage well such that the cylinder hangs inside the overflow water from the weir. Any change in the water level would affect the vertical thrust on the submersible cylinder. The output proportional to the water level (and flow) to be transmitted to the observation room through a four core jelly filled cable.
Type	Vibrating wire
Flow range	100 litre/second
Over range capacity	150%
Sensitivity	0.01 litre with read-out unit
Accuracy	± 1% F.S.
Operating temperature	-20 to 60^{o}C
(b) Mechanical type	Seepage measurement system shall be designed to measure a flow rate of around 0 to 50 litre/second. The seepage water would be collected in a concrete reservoir (by the civil contractor) with suitable filters to make the flow as nearly streamline as possible and made to flow over a V-notch weir. The rate of seepage water flow is calculated from the level of water over the weir. The V-notch weir is graduated directly in flow in terms of litre/second.
The instrument shall conform to IS 7436 (Part 1)	

Table B-3 Typical Specifications for Temperature Sensor

The equipment should conform to the following technical specifications:

Feature		Value
Site Conditions	Operating temperature range	-20 to + 60°C
	Operating humidity	5 to 100%
	Altitude	0 to 2500 metres
Sensor	Type	Resistance type
	Coil resistance	140 to 160 Ohm @ 25°C
	Surge arrestor	Citel 90 V gas discharge tube
	Over range	0 to +80 °C
	Over range effect	±0.1% F.S. up to 150%
	Resolution	0.05°C
	Accuracy	1% F.S.
	Dimensions	Approximately 20 mm diameter x 120 mm length
	Cable	1m, 2 core shielded
	Linearity	<0.5% F.S
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
General Features	Enclosure	Stainless steel
	Accessories	Sensor mounting support, cables and other accessories as required
	Protection	IP 68 or NEMA-4
	Manuals	Full documentation and maintenance manual in English

Table B-4 Typical Specifications for Joint meter / Crack meter

The equipment should conform to the following technical specifications:

Feature		Value
Site Conditions	Operating temperature range	-20 to + 60°C
	Operating humidity	5 to 100%
	Altitude	0 to 2500 metres
Sensor	Type	Vibrating wire
	Operating range	12.5mm, 25mm, 50mm (Project specific)
	Over range	1.25 x Range
	Resolution	0.025% F. S
	Accuracy	±0.2% F.S (±0.1% F.S. optional)
	Linearity	<0.5% F.S
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
General Features	Enclosure	Stainless steel, IP 68
	Accessories	Sensor mounting support, cables and other accessories as required
	Protection	IP 68 or NEMA-4
	Manuals	Full documentation and maintenance manual in English

Table B-5 Typical Specifications for Normal Plumb Line

The equipment offered should conform to the following technical specifications:

Feature		Value
Site Conditions	Operating temperature range	-20 to + 60°C
	Operating humidity	5 to 100%
	Altitude	0 to 2500 metres
Measuring method / Sensor	Measuring method	Travelling telescope
	Focus range	250 to 500 mm
	Measuring range	± 50 mm ±75 mm (Project Specific)
	Table size	625 x 625 mm (approximately)
	Resolution	0.01 mm
	Suspension wire	Stainless steel wire 1 mm diameter suspended from hollow float in tank filled with water.
	Accuracy	0.1 mm
	Suspension Weight	10 kg.
	Oil Tank	PVC 40 litre capacity
	Damping oil	SAE 40
	Linearity	--
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
General Features	Accessories	Mounting support, cables and other accessories as required
	Manuals	Full documentation and maintenance manual in English

Table B-6 Typical Specifications for Inverted Plumb Line

The equipment should conform to the following technical specifications:

Feature		Value
Site Conditions	Operating temperature range	-20 to + 60°C
	Operating humidity	5 to 100%
	Altitude	0 to 2500 metres
Measuring method / Sensor	Measuring method	Travelling telescope
	Focus range	250 to 500 mm (Project Specific)
	Measuring range	± 50 mm
	Table size	625 x 625 mm (approximately)
	Resolution	0.01 mm
	Suspension wire	Stainless steel wire 1 mm diameter suspended from collet on a rectangular bar grouted at the top
	Accuracy	0.1 mm
	Suspension Weight	8 kg.
	Oil Tank	Fibreglass, 800 mm diameter x 500 mm height
	Float material	PVC
	Damping oil	SAE 40
	Linearity	--
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
General Features	Accessories	Mounting support, cables and other accessories as required
	Manuals	Full documentation and maintenance manual in English

Table B-7 Typical Specifications for Geodetic Instruments

The equipment should conform to the following technical specifications:

1. Total Station	
Automatic total station 0.5"	Automatic / manual total station with 0.5” second accuracy, least count 0.1, reflectorless range of 500 m, range with reflector of 4000 m, RS-232 interface communication side cover (USB-Host, USB-device ports and Bluetooth), laser plummet, quick guide and container with protective cover, single side keyboard supplied with all accessories
Manual total station 1"	Manual total station with 1-second accuracy, least count 0.1, reflectorless range of 500 m, range with reflector of 7500 m, RS-232 interface communication side cover (USB-Host, USB-device ports and Bluetooth), laser plummet, quick guide and container with protective cover, single side keyboard supplied with all accessories
2. Survey Targets Or Reflectors For Opto - Electronic Measurements	
Bi reflex targets	A convergence bolt made of 12 mm x 170 mm galvanized steel rebar with SS threaded stud shall be securely attached to the exposed rock or shotcrete surface. The bolt shall be provided with a plastic cap with a breaking point serving as an adapter for the mounting of a reflector with a marked centre point. This device shall be designed for high precision measurements with two axes of rotation and to be observable from both sides. The manufacturing accuracy must be better than ± 0.1 mm to achieve an overall accuracy of ± 1 mm within the measuring section. The targets must be replaceable without loss of precision.
Prism targets	i. Used if the distance from the total station is less than 140 m. ii. The plastic reflector shall be replaced by a positive-centred prism with the same standard as the reflector above. iii. Used if the distance from the total station is up to 600 m

Table B-8 Typical Specifications for Tilt Meter

The Tilt meter should conform to the following technical specifications:

Feature		Value
Site Conditions	Operating temperature range	-20 to + 60°C
	Operating humidity	5 to 100%
	Altitude	0 to 2500 metres
Sensor	Type	Vibrating wire / MEMS biaxial
	Operating range	±10 °C
	Temperature limit	Insulated enclosure
	Resolution	± 0.05 mm/m (8 arc seconds)
	Accuracy	±0.1% F. S.
	Size (l x b x h)	162 x 90 x 145 mm (App.)
	Tilt plate size	142 x 24 mm high (App.) aluminium alloy
	Cable	4 core shielded
	Linearity	--
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
General Features	Enclosure	Stainless steel
	Accessories	Sensor mounting support, cables and other accessories as required
	Protection	IP 68 or NEMA-4
	Manuals	Full documentation and maintenance manual in English

Table B-9 Typical Specifications for Inclinometers

The equipment should comply with the following technical specifications:

Feature		Value
Site Conditions	Operating temperature range	-20 to + 60°C
	Operating humidity	5 to 100%
	Altitude	0 to 2500 metres
Sensor	Sensor Type	Vibrating wire
	Operating range	± 15°
	Resolution	0.01 mm
	Accuracy	± 0.02% FS.
	Power supply 10	15 V DC
	Linearity	--
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
General Features	Enclosure	Stainless steel
	Accessories	Special casing tubes and fixtures for connection
	Protection	IP 68 or NEMA-4
	Manuals	Full documentation and maintenance manual in English

Table B-10 Typical Specifications for Multiple Point (3 point & 5 point) Bore Hole Extensometer

The equipment should conform to the following technical specifications:

Feature		Value
Site Conditions	Operating temperature range	-20 to + 60°C
	Operating humidity	5 to 100%
	Altitude	0 to 2500 metres
Sensor	Sensor Type	Vibrating wire
	Operating range	100 mm
	Resolution	0.01 mm
	Accuracy	± 0.5 mm
	Linearity	--
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
General Features	Enclosure	Stainless steel
	Accessories	Connecting rods, protective pipes, measuring head assembly, grouting jigs, hydraulically inflatable anchors
	Protection	IP 68 or NEMA-4
	Manuals	Full documentation and maintenance manual in English

Table B-11 Typical Specifications for Stress Meter (for Concrete/Masonry dams)

The equipment should comply with the following technical specifications:

Feature		Value
Site Conditions	Operating temperature range	-20 to + 60°C
	Operating humidity	5 to 100%
	Altitude	0 to 2500 metres
Sensor	Type	Vibrating wire with thermistor
	Thermistor	Temperature compensated
	Operating range	± 80 kg/cm^2
	Over range limit	150% of range
	Resolution	10 kPa (0.1 kg/cm2) with readout unit
	Accuracy	± 0.5% FS normal ± 0.1% FS optional
	Linearity	--
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
General Features	Enclosure	Stainless steel
	Accessories	--
	Protection	IP 68 or NEMA-4
	Manuals	Full documentation and maintenance manual in English

Table B-12 Typical Specifications for Strain Meter (For Concrete/Masonry dams)

The equipment should comply with the following technical specifications:

Feature		Value
Site Conditions	Operating temperature range	-20 to + 60°C
	Operating humidity	5 to 100%
	Altitude	0 to 2500 metres
Sensor	Type	Vibrating wire with thermistor
	Thermistor	Temperature compensated
	Operating range	± 1500 με (Microstrain)
	Over range limit	150% of range
	Resolution	± 1 με (Microstrain)unit
	Accuracy	± 0.5% FS normal ± 0.1% FS optional
	Linearity	< 0.5% FS
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
	Vibration resistance	Mechanical vibrations with 4 g and 5 to 100 Hz
	Frequency datum	800 Hz or more
	Surge protection	1.5 KVA
	Cable Type	4 conductor to twisted pair, 22 A WG
	Thermal co-efficient of expansion	12.0 ppm / ºC
	Temperature sensitivity	5 mm over operating temperature range
General Features	Enclosure	Stainless steel
	Accessories	--
	Protection	IP 68 or NEMA-4
	Manuals	Full documentation and maintenance manual in English

Table B-13 Typical Specifications for No Stress/Strain Meter

The equipment should comply with the following technical specifications:

Feature		Value
Site Conditions	Operating temperature range	-20 to + 60°C
	Operating humidity	5 to 100%
	Altitude	0 to 2500 metres
Sensor	Type	Vibrating wire with thermistor
	Thermistor	Temperature compensated
	Operating range	± 1500 με (microstrain)
	Over range limit	150% of range
	Resolution	± 1 με (Microstrain)
	Accuracy	± 0.5% FS normal ± 0.1% FS optional
	Linearity	--
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
	Vibration resistance	Mechanical vibrations with 4 g and 5 to 100 Hz
	Frequency datum	800 Hz or more
	Surge protection	1.5 KVA
General Features	Enclosure	Stainless steel
	Accessories	--
	Protection	IP 68 or NEMA-4
	Manuals	Full documentation and maintenance manual in English

Table B-14 Typical Specifications for Piezometer / Pore Pressure Cell (Vibrating Wire Type)

The equipment should conform to the following technical specifications:

Feature		Value
Site Conditions	Operating temperature range	-20 to + 60°C
	Compensated	From 0 to +60^{o}C
	Temperature compensation	Inbuilt
	Operating humidity	5 to 100%
	Altitude	0 to 2500 metres
Sensor	Sensor Type	Vibrating wire piezometer in stainless steel housing with stainless steel filter stone, thermistor, unvented
	Operating range	3 kg/cm^2 , 5 kg/cm^2 , 7.5 kg/cm^2 , 10 kg/cm^2 (Project Specific)
	Over range	1.5 x rated pressure
	Over range effect	±0.1% F.S. up to 150%
	Resolution	0.025% F. S (minimum)
	Output interface	SDI-12 / RS 485 / 4-20 mA /compatible with data logger
	Accuracy	±0.1% F. S.
	Power supply	10 - 15 V DC
	Linearity	<0.5% F.S.
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
General Features	Enclosure	Stainless steel
	Accessories	Sensor mounting support, cables and other accessories as required
	Protection	IP 68 or NEMA-4
	Manuals	Full documentation and maintenance manual in English

Table B-15 A Typical Specifications for Strong Motion Accelerographs (Built-In-Accelerometer)

The equipment should conform to the following technical specifications:

Feature	Value
Transducers	Triaxial, force balanced, orthogonal oriented transducers (two horizontal and one vertical) along with the data acquisition system in a single sealed unit.
Full scale Range	User selectable +0.5 g, +1 g, +2 g, +4 g
Frequency response	Flat (within +3dB) to ground acceleration in the range of DC to at least 200Hz
Dynamic range of accelerometer	>130 dB
Linearity	Better than 1% of full scale
Cross axis sensitivity	Less than 1% of full scale
Clip level	Greater than the full scale range
Leveling	Bubble level indicator for leveling the transducer.
Orientation	Suitable mark to indicate the direction of relative orientation of the transducer.
Frequency response curve and system information	Frequency response curve of the unit along with information regarding transfer function including poles, zeros and normalization factor should be provided (for each sensor as per the serial number)
Calibration	Calibration facility from the data acquisition system locally or remotely from central recording station through DAS
Anchoring	Provision for anchoring the Accelerograph unit to the seismic pier.
Number of channels	Three
ADC	Independent 24-bit digitizers, one for each channel
Sampling rate	User selectable upto 1000 SPS per channel
Dynamic range of A/D converter	130dB or more @ 100sps
Input voltage range of A/D converter	to be matched with the accelerometer output
Channel-to-channel skew	None
System response	±3 dB flat from DC to nyquist frequency

Feature	Value
Noise level	Noise level of the unit including the accelerometer and the data acquisition system should be less than 0.001% of the full scale level in the frequency range from DC to 50Hz
Timing System	i) Internal GPS receiver based timing system ii) Timing accuracy of +10μsec or less when GPS is locked iii) Record of GPS status information iv) GPS antenna should be enclosed in weather proof sealed enclosure with lightning protection.
Recording mode	i) Both continuous and triggered recording mode ii) Triggering: The DAS should be capable of recording the acceleration data in the STA/LTA ratio trigger, threshold trigger and time window iii) Trigger selection: Independent selection for each channel iv) Pre-event Recording length: User selectable from 1 to 30 sec in steps of 1 sec v) Post event length: User selectable up to 90 sec or more
Data storage	i) User accessible compact flash card ii) The compact flash card should have the capacity of 32GB or more. iii) The compact flash card should be rugged and industrial grade suitable to withstand extreme temperature variations. iv) The bidder should attach the data sheet of the compact flash card to be supplied with the DAS.
Recording format	i) Standard seismic data in a format that is compatible with Windows and Linux platforms. ii) Conversion utilities to miniseed, SAC, SEISAN, ASCII formats to be provided.
DAS firmware should support	i) Web browsing support/ communication over TCP/ IP protocol. ii) Full Duplex communication between field station and Central Receiving Station (CRS) iii) Triggered or continuous data transmission iv) Support off-the- shelf communication equipment v) Extensive error correction vi) The DAS should be capable of recording the accelerometer data on the local compact flash card as well as support realtime data telemetry to a central site through VSAT telemetry network simultaneously.

Feature	Value
DAS firmware should support	vii) DAS should have facility to retrieve the old data in the compact flash card from Central Recording Station manually through VSAT network. viii) DAS should have the facility to check the state of health of the system including system voltage, temperature, GPS status etc. ix) DAS should be able to issue an alert and start the communication in case of earthquake detection or failure of state of health parameter. x) DAS should have the facility for Calibration of the Accelerometer
Communication	i) Ethernet Interface for real time telemetry ii) RS-232 interface for real time telemetry / parameter setup iii) In built modem iv) Ethernet port, RS-232 port, USB port should be provided
Power	i) Total Power consumption < 3.0 watts at 12V DC (including accelerometer and DAS) ii) Status display indicators for power to be provided iii) Provision to connect external 12V battery source iv) Supply power isolated from signal ground v) Reverse voltage protection vi) Over voltage protection vii) DAS should resume data acquisition automatically when the power is restored after disruption.
Operating temperature	-20° to 60° C
Humidity	Up to 100% RH
Enclosure	Accelerometer and DAS should be enclosed in weather and shock proof sealed single enclosure with lightning protection.
Cables	i) Power cable to external Battery of 2m length to be provided with each unit ii) The Ethernet cable to connect DAS to VSAT IDU with end connectors (2m length) to be provided iii) DAS-GPS antenna cable length of at least 20 meters length with end connectors
Notes	i) All the hardware, software and cables required for parameter setting, data retrieval from the DAS at field seismic station and data storage should be provided and described. ii) Detailed user manual, data sheet and calibration data sheet of the Accelerograph should be provided.

Table B-15 B Typical Specifications for Broadband Seismometers

The equipment should conform to the following technical specifications:

Feature	Value
Transducers	Tri-axial, force-balanced, broadband velocity transducer with electronic feedback in a single sealed module.
Frequency response	Flat response (within +/- 3dB) to ground velocity in the range of 120 secs to 50Hz.
Dynamic range	≥ 135 dB @ 5Hz.
Output voltage	± 20V
Damping	0.7 of critical
Generator constant	Atleast 750 V/m/sec.
Linearity	Better than 1% of full scale
Cross axis sensitivity	Less than 1 % of full scale
Mass centering	Mass centering automatic on external command locally and remotely from the central recording station through DAS. Control unit for mass position monitoring and mass centering (if any) to be provided.
Calibration facility	Calibration facility from Data Acquisition System
Frequency response curve	Frequency response curve of the unit along with information regarding transfer function including poles and zeros should be provided (for each sensor as per the serial number)
Noise response	Noise response must be below the USGS Low Noise Model in the frequency range of 35 secs to 5 Hz. Test reports of the sensor noise over the full pass band should be provided.
Leveling	Bubble level indicator for leveling the transducer.
Orientation	Suitable mark to indicate the direction of relative orientation of the transducer
Mass locking	Mass locking Should have a robust locking and safety mechanism during transportation
Enclosure	The sensor should be housed in a shockproof and waterproof enclosure.
Cabling	Low-loss shielded Seismometer-DAS cable of at least 20 meters with end connectors.
Connectors	The connectors also should be waterproof and rust proof
Operating temperature range	–20° to 60°C
Humidity	up to 100% RH
Power consumption	< 2.0 watts at 12V DC
Protections	1. Reverse voltage protection 2. Over voltage protection Thermal insulation cover An airtight thermal insulation cover should be provided carry case Rugged field carry case for seismometer should be provided.
Supporting documents	Detailed user manual / data sheets / calibration data sheet to be provided

Table B-16 A Typical Specifications for Radar Type Water Level Sensor

The equipment should conform to the following technical specifications:

Feature		Value
Site Conditions	Operating ambient temperature range	-20 to + 60°C
	Operating humidity	0 to 100%
	Altitude	0 to 2500 metres
Sensor	Sensor Type	Microwave non-contact sensor
	Thermistor	Temperature compensated
	Operating range	15 m/20 m/35 m/40 m/70 m/75 m
	Resolution	3 mm or less
	Accuracy	0.02% FSO
	Beam angle:	≤ 16 °
	Output interface	SDI-12 / RS 485 / 4-20 mA / compatible with data logger
	Power supply	10-15 V DC
	Linearity	--
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
General Features	Material	Corrosion resistance metal (stainless steel / aluminium or PVC)
	Enclosure	The sensor shall be easy to dismount and replace in the event of a malfunction.
	Tools	Complete tool kit for operation and routine maintenance
	Accessories	Sensor mounting support, cables and other accessories as required
	Protection	IP 65 or NEMA-4
	Manuals	Full documentation and maintenance manual in English
	`Horizontal mounting / installation arrangements	Above FRL, below a bridge girder wherever available otherwise horizontal cantilever arrangement from a mast /wall / pedestal
	Radar sensor should have display feature for diagnostic purpose	

Table B-16 B Typical Specifications for Shaft Encoder Type Water Level Sensor

The equipment should conform to the following technical specifications:

Feature		Value
Site Conditions	Operating ambient temperature range	From -20 to + 60 °C
	Operating humidity	5 to 100%
	Altitude	0 to 2500 metres
Sensor	Sensor Type	Shaft encoder based incremental rotary position sensor with digital display
	Range	1 to 100 metres
	Resolution	3 mm or less
	Accuracy	0.025% FSO
	Output interface	SDI-12 / RS 485 / 4-20 mA / compatible with data logger
	Power supply	12 V DC or switch rated for 12 V DC
	Linearity	--
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
General Features	Material	Corrosion resistance metal (stainless steel or aluminium)
	Enclosure	Lockable (key) box provided by the supplier to be mounted in a stilling well or gauge hut, with IP65 or NEMA 4 protection
	Tools	Complete tool kit for operation and routine maintenance
	Graduated tape	The tape should be of high quality to withstand a harsh and humid environment, should not get twisted or wrinkled during operation.
	Accessories	Sensor mounting support, floats, graduated tapes (metric), wheel, counterweight, and cabling
	Protection	NEMA 4 or IP65
	Manuals	Full documentation and maintenance manual in English

Table B-16 C Typical Specifications for Ultrasonic Sensor Type Water Level Sensor

The equipment should conform to the following technical specifications:

Feature		Value
Site Conditions	Operating ambient temperature range	From -20 to + 60 °C
	Operating humidity	0 to 100%
	Altitude	0 to 2500 metres
Sensor	Sensor Type	Ultrasonic non-contact sensor
	Range	Up to 10 metres
	Resolution	3 mm or less
	Accuracy	0.02% FSO
	Output interface	SDI-12 / RS 485 / 4-20 mA / compatible with data logger
	Power supply	10-15 V DC
	Linearity	--
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
General Features	Material	Corrosion resistance metal (stainless steel/ aluminium or PVC)
	Enclosure	The sensor shall be easy to dismount and replace in the event of a malfunction.
	Tools	Complete tool kit for operation and routine maintenance
	Graduated tape	The tape should be of high quality to withstand a harsh and humid environment, should not get twisted or wrinkled during operation.
	Accessories	Sensor mounting support, cables and other accessories as required
	Protection	NEMA 4 or IP65
	Manuals	Full documentation and maintenance manual in English

Table B-16 D Typical Specifications for Bubbler Type Water Level Sensor

The equipment should conform to the following technical specifications:

Feature		Value
Site Conditions	Operating ambient temperature range	From -20 to + 60 °C
	Operating humidity	0 to 100%
	Altitude	0 to 2500 metres
Sensor	Sensor Type	Continuous bubbling system and non-submersible transducer
	Range	15 to 30 psi (0.1 to 0.2 MPa)
	Resolution	0.0001 psi or less (0.7 Pa or less)
	Accuracy	0.1% FSO
	Output interface	SDI-12 / 4-20 mA / RS485, compatible with data logger
	Power supply	11 to 15 V DC
	Average current draw	<15 mA based on 1 bubble per second
	Purge	Manual line purge
	Bubble rate	Programmable 30 to 120 bubbles per minute
	Desiccators	The bubbling mechanism and the non-submersible transducer must be equipped with a desiccating system to keep the system from malfunctioning for a period not less than one year.
	Linearity	--
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
General Features	Tools	Complete tool kit for installation and routine maintenance
	Accessories	Sensor mounting support, cables and other accessories as required
	Protection	NEMA 4 or IP65
	Manuals	Full documentation and maintenance manual in English

Table B-16 E Typical Specifications for Pressure Transducer Type Water Level Sensor

The equipment should conform to the following technical specifications:

Feature		Value
Site Conditions	Operating ambient temperature range	From -20 to + 60 °C
	Operating humidity	0 to 100%
	Altitude	0 to 2500 metres
Sensor	Sensor Type	Pressure Sensor
	Range	Up to 30 metres of water column
	Resolution	3mm or less
	Accuracy	0.02% FSO
	Output interface	SDI-12 / RS 485 / 4-20 mA / compatible with data logger
	Power supply	10 to 15 V DC
	Average current draw	<15 mA based on 1 bubble per second
	Linearity	--
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
General Features	Material	Corrosion resistance metal (stainless steel/ aluminium or PVC)
	Enclosure	The sensor shall be easy to dismount and replace in the case of a malfunction.
	Tools	Complete tool kit for operation and routine maintenance
	Accessories	Sensor mounting support, cables and other accessories as required
	Protection	NEMA 4 or IP65
	Manuals	Full documentation and maintenance manual in English

Table B-17 Typical Specifications for Automatic Rain Gauge

The equipment should conform to the following technical specifications:

Feature		Value
Site Conditions	Operating ambient temperature range	-20 to + 60°C
	Operating humidity	0 to 100%
	Altitude	0 to 2500 metres
Sensor	Sensor Type	Tipping bucket with siphon
	Range	0 to 500 mm/h
	Material	UV resistant plastic or corrosion-resistant metal (aluminium, stainless steel), shock and vibration resistant
	Rim Diameter	Receiver/collecting funnel diameter: 200 ± 0.3 mm diameter with machined aluminium 200 mm rim or equivalent
	Resolution	0.2 mm
	Accuracy	2% of intensity (up to 10 cm/h)
	Output interface	SDI-12 / RS 485 / 4-20 mA / compatible with data logger
	Power supply	12 V DC or switch rated for 12 V DC
	Linearity	--
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
General Features	Material	Corrosion resistance metal (stainless steel / aluminium or PVC)
	Enclosure	Lockable (key) box provided by the supplier to be mounted in Stilling well or Gauge hut, with IP65 or NEMA 4 protection
	Tools	Complete tool kit for operation and routine maintenance
	Accessories	Sensor Mounting support, cables (power and signal), and other accessories as required. Complete tool kit for installation and routine maintenance giving full details.
	Protection	IP 65 or NEMA-4
	Graduated tape	The tape should be of high quality to withstand a harsh and humid environment, should not get twisted or wrinkled during operation.
	Manuals	Full documentation and maintenance manual in English

Table B-18 Typical Specifications for Automatic Weather Station

The equipment should conform to the following technical specifications:

Feature		Value
Site Conditions	Operating ambient temperature range	From -20 to + 60 °C
	Operating humidity	0 to 100%
	Altitude	0 to 2500 metres
Air Temperature Sensor	Sensor type	Platinum resistance or less or equivalent
	Range	-20 to +60 °C
	Resolution	± 0.1 °C
	Accuracy	Within ± 0.2 °C in the entire working range
	Response time	10 second or less
	Self-aspirated	To ensure a continuous supply of air. free from turbulence, water droplets and radiation
	Power supply	12 V DC or switch rated for 12 VDC
	Accessories	All accessories for mounting the instrument; e.g. special cross arm clamps or flag, if any, shall be provided.
	Linearity	--
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
Relative Humidity Sensor	Sensor type	Capacitive/ solid state humidity sensor
	Range	0 to 100%
	Resolution	1%
	Accuracy	±3% or less
	Power supply	12 V DC or switch rated for 12 V DC
	Response time	10 seconds or less
	Linearity	--
	Damping	--
	Skewness	--
	Digitization rate	--
	Lightning protection	Required
Wind Speed and Direction sensor	Sensor type	Ultrasonic sensor (no moving parts)
	Range	0 to 60 m/s for speed and 0 to 360 degrees for direction or better
	Resolution	0.1 m/s for Speed; + 1 degree for direction
	Accuracy	+ 0.5 m/s or less for wind speed, + 5 degree or less for wind direction
	Response time	Less than 1 second lag in operating range

Feature		Value
	Mounting	All accessories for mounting the instrument e.g. special cross arm clamps or flag if any shall be provided.
	Linearity	--
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
Air Pressure Sensor	Sensor type	Temperature compensated
	Range	600 to 1200 hPa
	Resolution	± 0.1 hPa
	Accuracy	± 0.2 hPa
	Power supply	12 V DC or switch rated for 12 V DC
	Linearity	--
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
Solar Radiation	Sensor type	ISO Class 1 Pyranometer (CMP 11 or better)
	Threshold	120 W/m^2 of direct solar irradiance
	Methodology	Alternate shading of sensor to account for sky radiation
	Spectral range	400 nm to 1100 nm
	Range	0 to 2000 W/m^2
	Resolution	1 W/m^2
	Accuracy (including temperature compensation)	3% or less
	Linearity	--
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
Evaporation- Pan Specification	Operating temperature	-20 to 60 ^oC
	Diameter of the pan	1.2 m or more
	Accuracy	+/- 1%
	Accessories	As required for complete installation of the sensors and equipment
	Material	Clean cast seamless acrylic plastic tubing or brass sheet
	Platform	Rot resistant timber treated with creosote or another effective wood preservative.
	Graduation	In millimetres.

Feature		Value
	Linearity	--
	Damping	--
	Skewness	--
	Digitisation rate	--
	Lightning protection	Required
General Features	Material	Corrosion resistance metal (stainless steel, aluminium, or PVC)
	Tools	Complete tool kit for operation and routine maintenance
	Accessories	Sensor mounting support, cables and other accessories as required
	Manuals	Full documentation and maintenance manual in English
	Output interface	SDI 12/RS 485/ 4-20 mA/ compatible with data logger

Table B-19 Typical Specifications Data Acquisition Systems (DAS) & its Accessories

Feature	Value
Number of channels	Three
ADC resolution	Three independent 24-bits digitizers, one for each channel
Dynamic range	Greater than or equal to 135dB @ 100sps.
Input Full scale	Range should match the sensor output with full scale at ±20V (40Vpp)
Common mode rejection ratio	Greater than 70dB
Electromagnetic interference	Immunity to Electromagnetic interference
System noise	The overall system noise should not be more than 2-3 counts of 24-bits system on a RMS basis in the frequency range of 0.00833 to 50Hz.
Sampling rate	1) User-selectable up to 500 sps per channel in the different data streams (at least two or more). 2) Simultaneous recording at different sampling rates in different streams (two or more), both in continuous and trigger modes.
Trigger parameters	Trigger parameters should be user selectable.
Gain	User selectable multiple gain settings
Sensor control	1) Calibration facility for Broadband seismometer 2) Mass position monitoring for Broadband seismometer 3) Mass centering on command for Broadband seismometer
RAM	At least 4 MB
Recording capacity	1) Mass storage media 16GB or more and hot swappable. 2) One spare mass storage media of same capacity for each digitizer to be supplied. 3) The mass storage media should be rugged and industrial grade suitable to withstand extreme temperature variations. The bidder should attach the data sheet of the mass storage media to be supplied with the DAS.
Recording mode	The DAS should be capable of recording on the local mass storage media as well as support real-time data telemetry to a central site through VSAT telemetry network simultaneously.
Recording format	Standard seismic data in a format that is compatible with Windows and Linux platforms with proven compression technique. Conversion utilities to SAC, SEISAN, ASCII formats to be supplied.
Communication ports	1) USB and / or serial port connectivity to a local terminal for parameter setting and data downloading 2) Ethernet port (10/ 100 Base- T) supporting TCP/IP. 3) The Ethernet cable to connect DAS to VSAT IDU with end connectors (length 2m) to be provided
DAS firmware	DAS firmware should support the following features: 1) Web browsing support/ communication over TCP/ IP protocol. 2) Full Duplex communication between field station and Central Receiving Station (CRS) Triggered or continuous data transmission. 3) Support off-the- shelf communication equipment

	4) Extensive error correction 5) Status display indicators for power, data acquisition, SOH, GPS status etc. should be provided on the front/top panel. 6) DAS should have facility to retrieve the old data in the storage media from Central Recording Station manually through VSAT network. 7) Provision for checking state of health information like battery voltage, temperature, memory used and available, GPS status, sensor mass position etc. locally and remotely from the central recording station.
GPS Timing system	1) UTC timed with digitally controlled precision VCXO clock phase locked to GPS 2) Timing accuracy less than 0.1mSec when GPS is locked 3) Free running TCXO accuracy of 1 ppm over wide temperature range. 4) GPS receiver electronic circuit should be inside the DAS with Antenna exposed outside. 5) Antenna cable length should be 20 mts or more with end connectors. 6) Antenna should be enclosed in water tight and can work effectively in extreme climatic condition. 7) Rust proof GPS mounting rod and accessories to be provided. 8) Antenna cable should be laid through thick plastic conduit pipe from roof-terrace to the digitizer.
Power requirements	1) Supply voltage 10-24V DC. 2) Power consumption: Less than 2W at 12V DC recording 3 channels at 100sps, continuous mode data acquisition 3) Supply power should be isolated from the signal ground 4) Reverse voltage protection 5) Low battery voltage protection 6) DAS power cable at least 2m length to be supplied 7) DAS should resume data acquisition automatically when the power is restored after disruption.
Operating temperature	-20° to 60°C
Humidity	Up to 100% RH
Housing	DAS and GPS units should be enclosed in weather and shock proof sealed enclosures with lightning protection.
Supporting documents	Detailed user manual and data sheet to be provided.
Additional hardware and software	The hardware and software required for parameter setting, data retrieval from the DAS at field seismic station and data storage should be provided and described.
Other essential requirements	1)A point-by-point statement of compliance of the technical specifications of the tender equipment should accompany the bid along with the explanations as to how the compliance is achieved. It should also be supported by illustrative literature / catalogues. 2) The supplier should provide all operation, service and maintenance manuals (in English) along with necessary circuit diagrams. 3) The bidder should provide the power consumption details of the

	broadband seismometers, data acquisition Systems and endurance of the internal batteries supplied with the unit. 4) The bidder should be able to supply spares for the quoted model of the broadband seismometers and the data acquisition Systems for five-year period. The spares required for five-year period may be quoted as optional items. 5) The bidder should propose any other hardware and software required at the field stations for installation and for the efficient operation and maintenance of the seismic stations. 6) The supplier must provide the necessary training on installation, operation, maintenance and calibration of the system including usage and the system application software at for the period of five days. The cost of such training program may be quoted separately.

Annexure - C

LIST OF BIS CODES FOR DAM INSTRUMENTATION

Standard Number	Year of Publication	Description
IS 4967	**1968**	Recommendations for seismic instrumentation for river valley projects [CED 39: Earthquake Engineering]
IS 6524	**1972**	Code of practice for installation and observation of instruments for temperature measurements inside dams; resistance type temperature meters [WRD 16: Hydraulic Structures Instrumentation]
IS 6532	**1972**	Code of practice for design, installation, observation and maintenance of uplift pressure pipes for hydraulic structures on permeable foundations [WRD 16: Hydraulic Structures Instrumentation]
IS 7356-1	**2002**	Code of Practice for Installation, Maintenance and Observation of Instruments for Pore Pressure Measurements in Earth Dams and Rockfill Dams, Part 1: Porous Tube Piezometers [WRD 16: Hydraulic Structures Instrumentation]
IS 7436-1	**1993**	Guide for types of measurements for structures in river valley projects and criteria for choice and location of measuring instruments, Part 1: For earth and rockfill dams [WRD 16: Hydraulic Structures Instrumentation]
IS 7436-2	**1997**	Guide for types of measurements for structures in river valley projects and criteria for choice and location of measuring instruments, Part 2: Concrete and masonry dams [WRD 16: Hydraulic Structures Instrumentation]
IS 7500	**2000**	Code of Practice for Installation and Observation of Cross Arms for Measurement of Internal Vertical Movement in Earth Dams [WRD 16: Hydraulic Structures Instrumentation]
IS 7356-2	**2003**	Installation, Observation and Maintenance of Instruments for Pore Pressure Measurements in Earth and Rockfill Dams - Code of Practice, Part 2: Twin Tube Hydraulic Piezometers [WRD 16: Hydraulic Structures Instrumentation]
IS 8226	**1976**	Code of practice for installation and observation of base plates for measurement of foundation settlement in embankments [WRD 16: Hydraulic Structures Instrumentation]
IS 8282-1	**1976**	Code of practice for installation, maintenance and observations of pore pressure measuring devices in concrete and masonry dams, Part 1: ***Electrical resistance type cell*** [WRD 16: Hydraulic Structures Instrumentation]
IS 8282-2	**1996**	Installation, Maintenance and Observations of Pore Pressure Measuring Devices in Concrete and Masonry Dams - Code of Practice, Part 2: ***Vibrating Wire Type Cell*** [WRD 16: Hydraulic Structures Instrumentation]
IS 10434-1	**2003**	Installation, Maintenance and Observation of Deformation Measuring Devices in Concrete and Masonry Dams - Guidelines, Part 1: ***Resistance Type Jointmeters*** [WRD 16: Hydraulic Structures Instrumentation]

IS 10434-2	**1996**	Guidelines for installation, maintenance and observation of deformation measuring devices in concrete and masonry dams, Part 2: ***Vibrating wire type joint meter*** [WRD 16: Hydraulic structures Instrumentation]
IS 12169	**1987**	Criteria for Design of Small Embankment Dams
IS 12949	**1990**	Code of practice for installation, maintenance and observation of instruments for pore pressure measurements in earth dams and rockfill dams: Electrical pore pressure cells - vibratory wire type [WRD 16: Hydraulic Structures Instrumentation]
IS 13073-1	**2002**	Installation, Maintenance and Observation of Displacement Measuring Devices in Concrete and Masonry Dams - Code of Practice, Part 1: ***Deflection Measurement Using Plumb Lines*** [WRD 16: Hydraulic Structures Instrumentation]
IS 13073-2	**2000**	Code of Practice for Installation, Maintenance and Observation of Displacement Measuring Devices for Concrete and Masonry Dams, Part 2: ***Geodetic Observation - Crest Collimation*** [WRD 16: Hydraulic Structures Instrumentation]
IS 13232	**1992**	Installation, maintenance and observations of ***electrical strain measuring devices*** in concrete dams - Code of practice [WRD 16: Hydraulic Structures Instrumentation]
IS 14278	**1995**	Stress measuring devices in concrete and masonry dams - Installation, commissioning and observations - Code of practice [WRD 16: Hydraulic Structures Instrumentation]
IS 14750	**2000**	Code of Practice for Installation, Maintenance and Observation of Seepage Measuring Devices for Concrete/Masonry and Earth/Rockfill Dams [WRD 16: Hydraulic Structures Instrumentation]
IS 14793	**2000**	Code of Practice for Installation, Maintenance and Observation of the Instruments for Vibration Studies Other Than Earthquakes [WRD 16: Hydraulic Structures Instrumentation]

LIST OF OTHER USEFUL BIS CODES RELATED TO DAM INSTRUMENTATION

Standard Number	Year of Publication	Description
IS 5225	**1992**	Meteorology - Raingauge, non recording
IS 5235	**1992**	Meteorology - Raingauge, recording
I.S. 9000(Part I) -	**1977**	Basic Environmental Testing Procedures for Electronic and Electrical Items, Part 1: General
SP 61	**1994**	General guidelines for automatic weather stations [PGD 21: Meteorological Instruments]

Annexure D

FORMAT FOR MONITORING STATUS OF INSTRUMENTATION

Sr.No	Instrument Name	Instrument Type (Vibrating/ Electrical/Pneumatic / Hydraulic/ Mechanical)	Block	Location	Date of Installation	Functional status	Name of manufacturer	Max/Min recorded value with unit	Current Value with unit	Remark
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**

FORMAT FOR UPLIFT PRESSURE PIPE OBSERVATIONS

As per IS: 6532 1972

Name of river:
Name of hydraulic structure:

Give the sketch of cross section along the line of pipes, of the structure showing details indicated in Note overleaf

Name of observer:
Date of observation:
Approximate time of observation ……………. h to a........... h
Upstream water level: ………………….(m)
Downstream water level: …………………. (m)
Head, H = ………………(m)
Shade temperature, maximum: ………..°C minimum: ………… °C
River water temperature: …………….°C
Depth of sediment on upstream pervious floor: …………….(m)
Depth of sediment on downstream pervious floor: …………(m)
Line No. ………… Total width of pucca floor: …………......

Pipe No.	Distance from Upstream End of Pucca Floor	Reduced Level of Bottom of Pipe	Reduced Level of Bend of Pipes, if Any
(1)	(2)	(3)	(4)

Pipe No.	Reduced Level of Top of Pipe, m	Pipe Water Temperature °C	Depth of water in pipe, m	Reduced level of water in pipe, m	P m	Φ=P/Hx100		Remarks
						Designed	Observed	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

Note -Following features may be shown on the sketch:
a) Foundation profile;
b) uplift pipes with their number (reduced levels of bottoms and tops of pipes, bends, if any, distance from upstream end of pucca floor; and
c) Stratification of the substrata.

FORMAT FOR RECORD OF OBSERVATIONS OF VIBRATING WIRE TYPE PORE PRESSURE CELL

(As per IS 8282 (Part 2) : 1996**)**

Project :

a) Instrument Name
b) Instrument Manufacturer :

Location :

Initial frequency f_o:

Calibration Temp (t_o) :

Calibration Factor (K) :

Temperature Coefficient (C) :

Zero Offsets (A) :

Pore Pressure $P = K[(f_o^2-f^2)+C(t-t_o)]+A$

Date	R.WL in m	Temp of Location of Cell (t)°C	Observed Frequency (*f*) Hz	Change in Frequency, (f_o-f)Hz	Pore Pressure (P) Bar	Pore Pressure in Metres of Water Head	Remarks

Observer's Signature:
Date:

FORMAT FOR STRAIN METER DATA
As per IS 13232:1992

Manufacturer's No ……………………………………………Strainmeter No…………..

Location…………Block.. . . . .Chainage... . . . . Sta... . . . .El. . . . .

Calibrations

Meter resistance of 0°F …………………………………. ohms

Change in temperature per ohm change in resistant ……………………………………^{o}F

Useful range ……………………………………………………………. ratio in percent

Original calibration constant ………………………..millionths per 0.01 percent ratio change

Calibration constant corrected for leads ……………millionths per percent 0.01 ratio change

Resistance of leads at 70°F…………………………………………………. ohms (pair)

Temperature correction ……………………………… millionths per ………. ^{o}F

Contraction Expansion

1	2	3	4	5	6	7	8	9	10	11
Date	Time	Observed	Change in Resistance	Indicated Temperature ^{o}F	Resistance Ratio, percent	Change in Ratio, percent	Indicated Unit Length Change, Millionths	Correction for Meter expansion, Millionths	Actual length Change, Millionths	Remarks

Annexure E

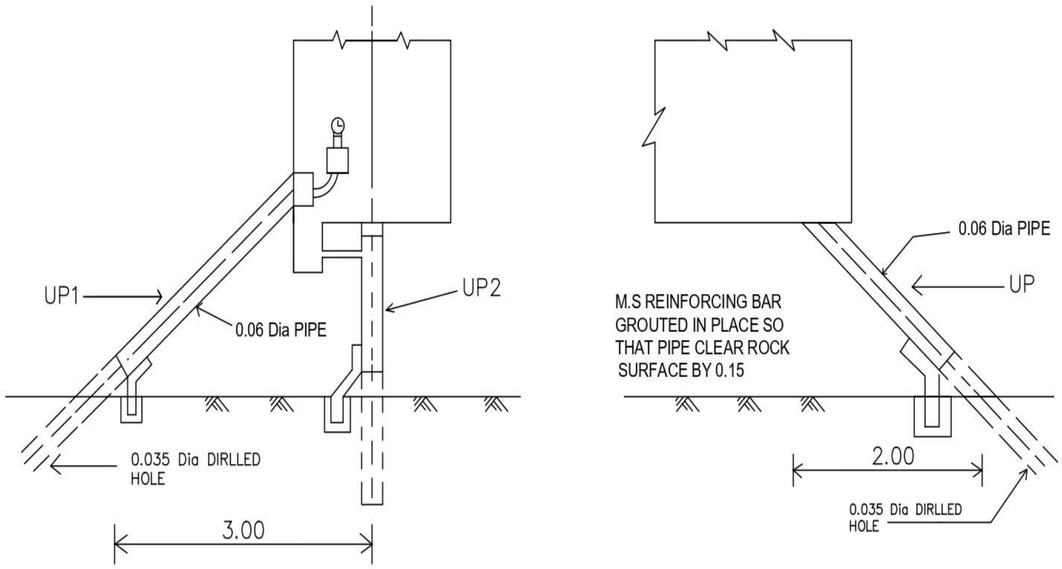


Figure E-1 INSTALLATION DETAILS OF UPLIFT PRESSURE PIPE

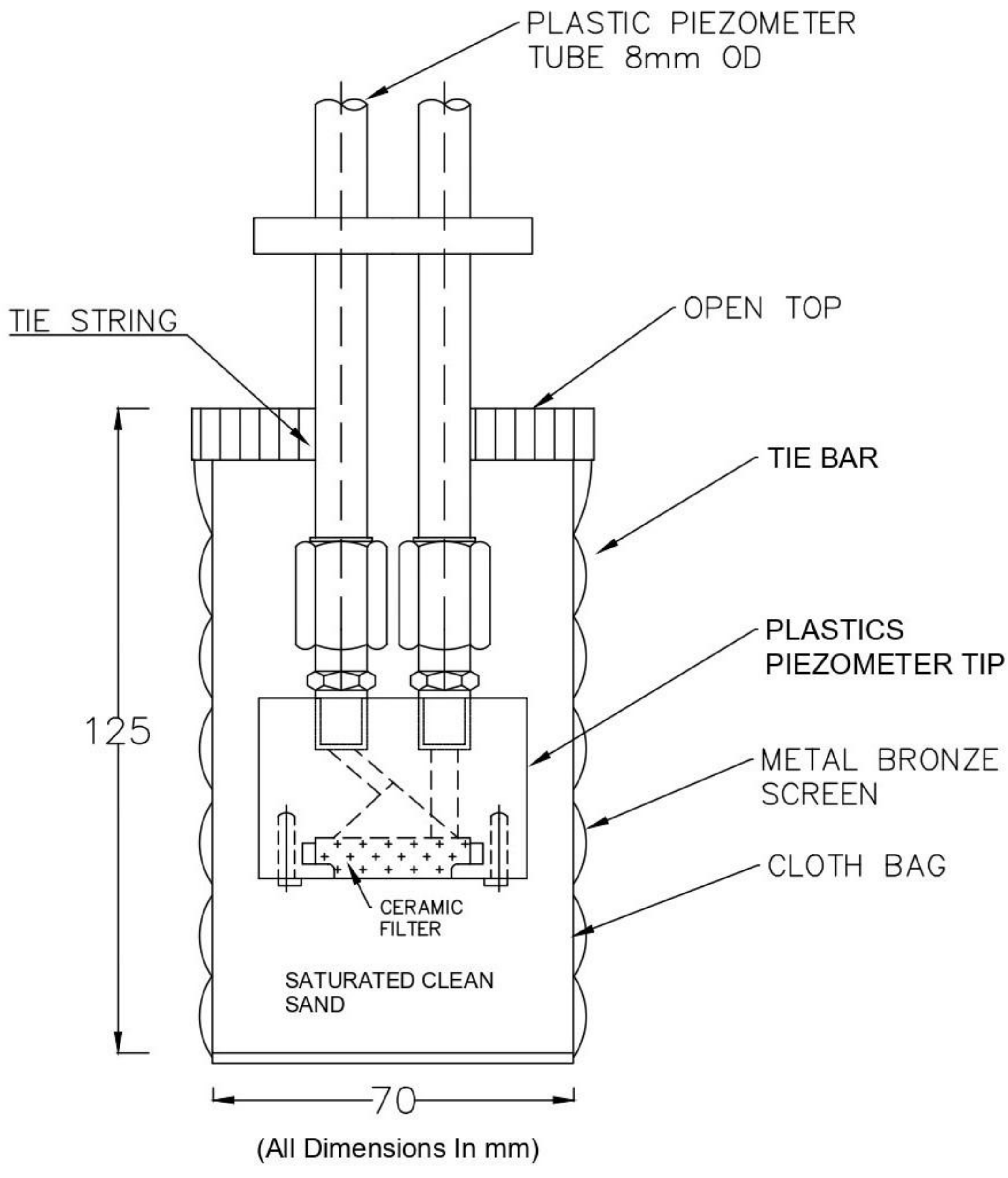


Figure E-2 FOUNDATION TYPE PIEZOMETER ASSEMBLY

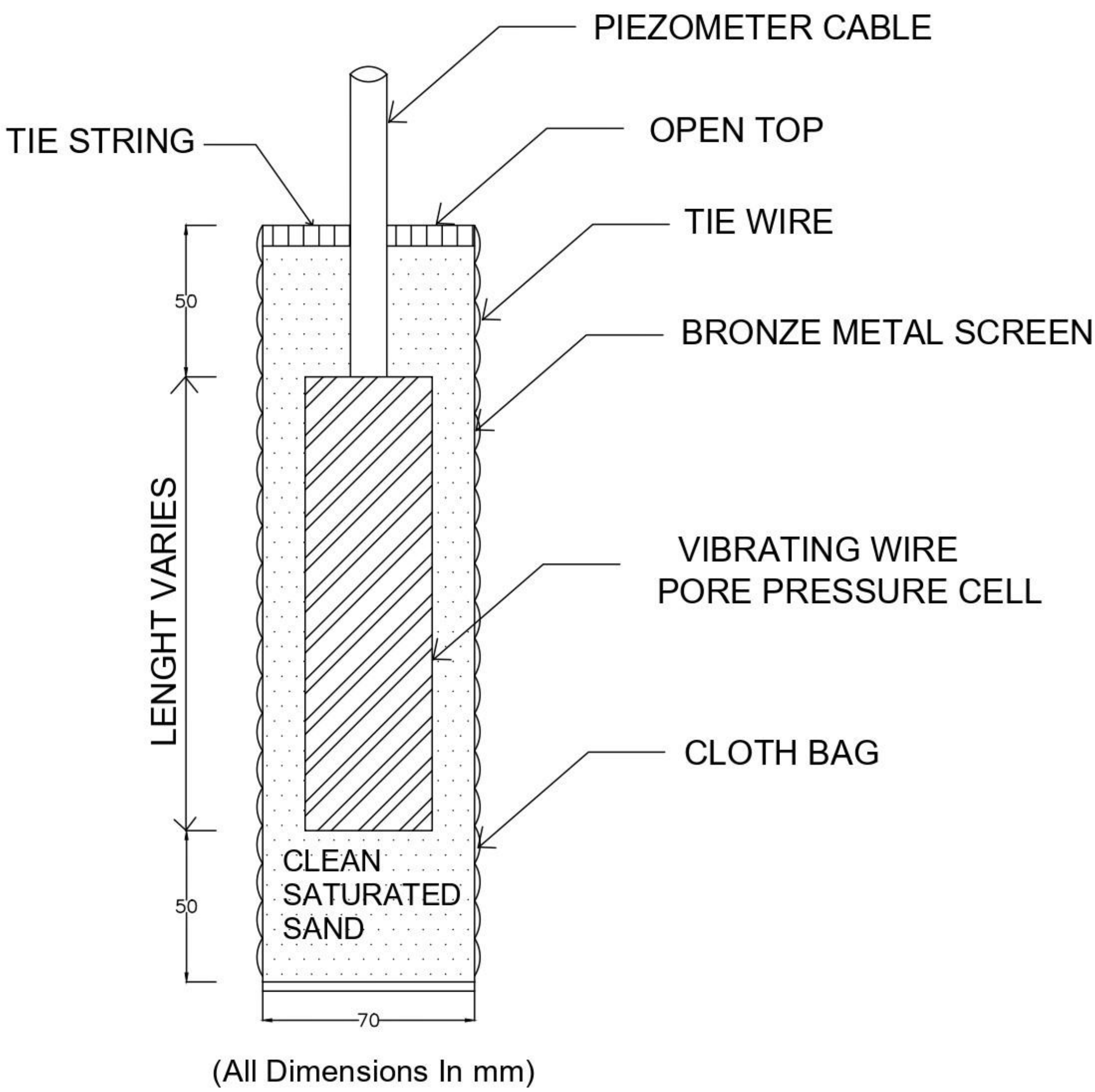
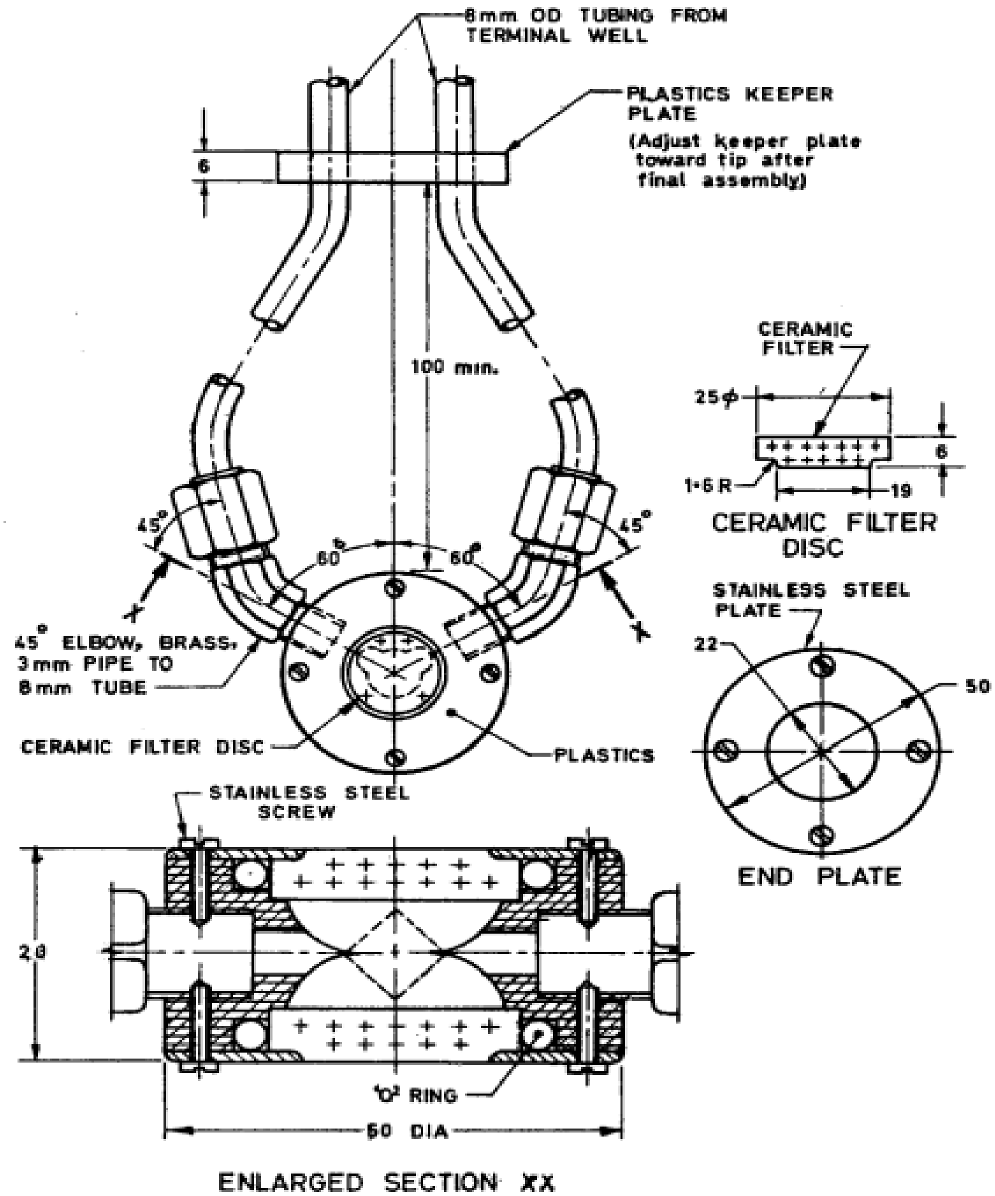
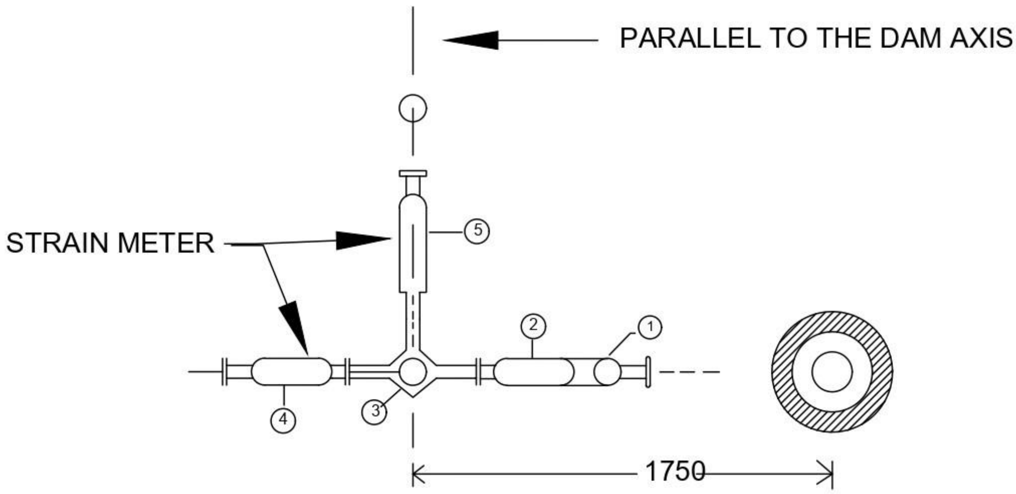


Figure E-3 PORE PRESSURE CELL ASSEMBLY FOR INSTALLATION IN DRILL HOLES

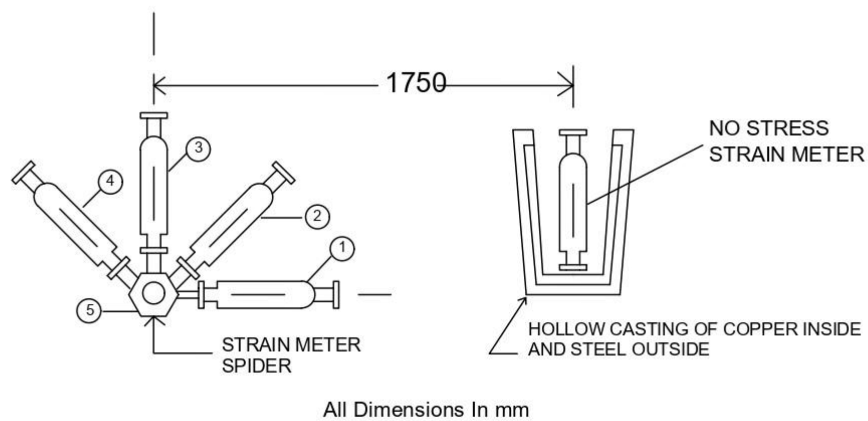


All dimensions in millimetres.

Figure E-4 EMBANKMENT TYPE PIEZOMETER TIP (WITH CERAMIC DISC)



PLAN



ELEVATION

FIGURE E-5 TYPICAL LAYOUT OF A GROUP OF 5 STRAINMETERS AND 1 NO-STRESS STRAIN METER

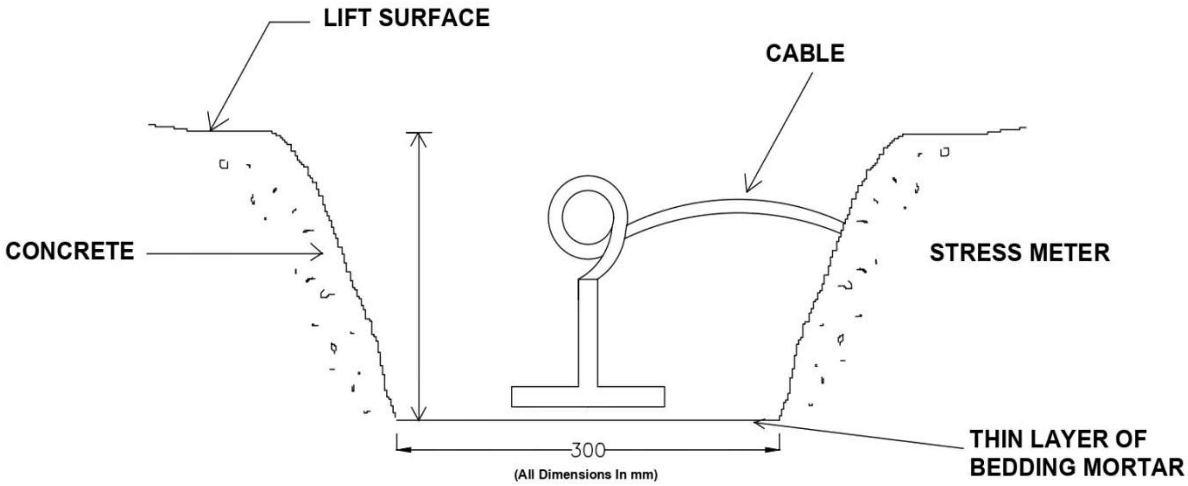


Figure E-6 INSTALLATION OF STRESS METER

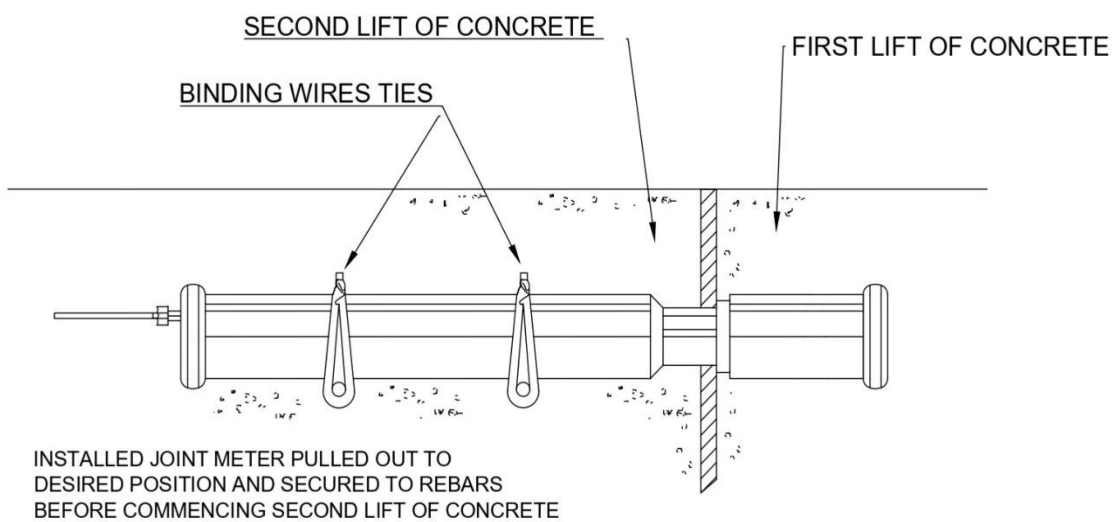


Figure E-7JOINTMETER INSTALLATION

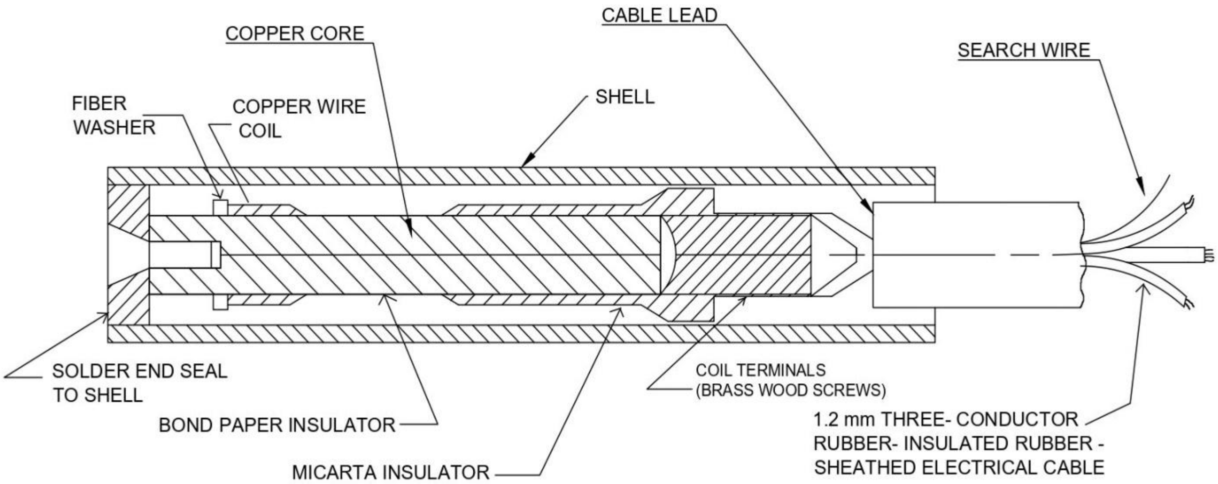


Figure E-8 EMBEDED TYPE RSISTANCE TEMPERATURE METER

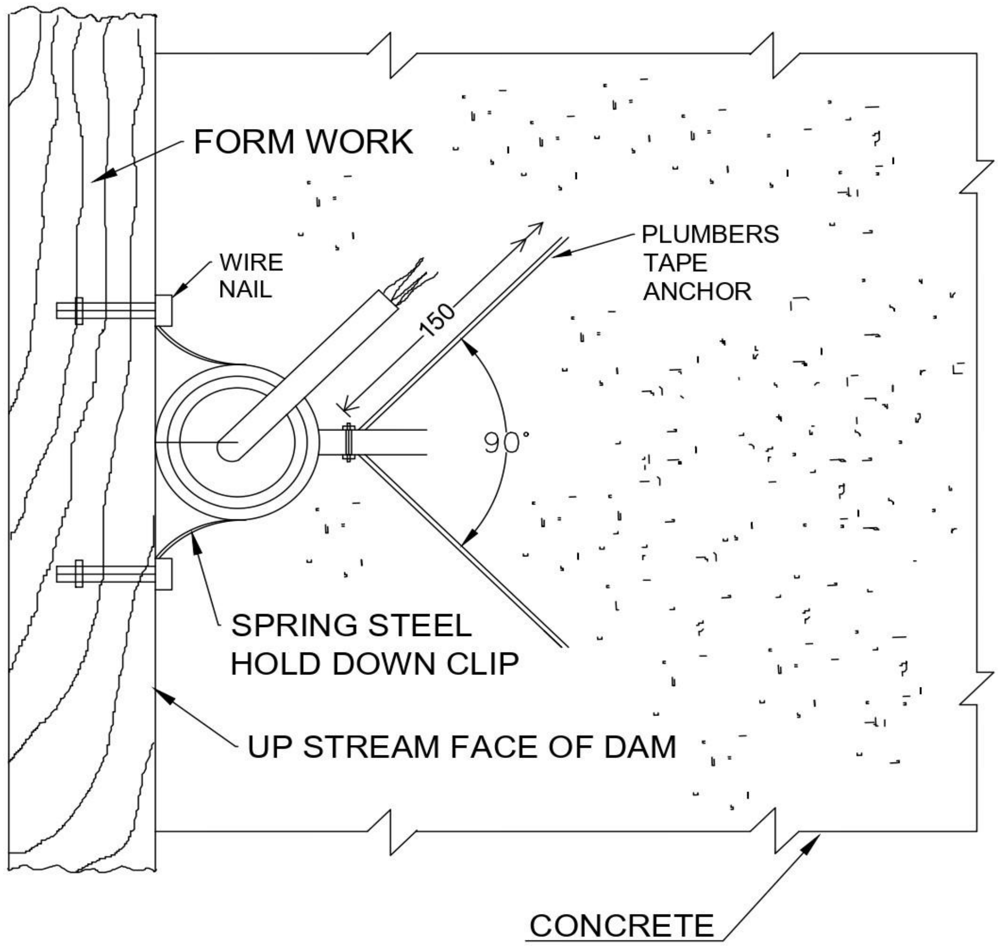


Figure E-9 TYPICAL LAYOUT OF SURFACE TEMPERATURE METER

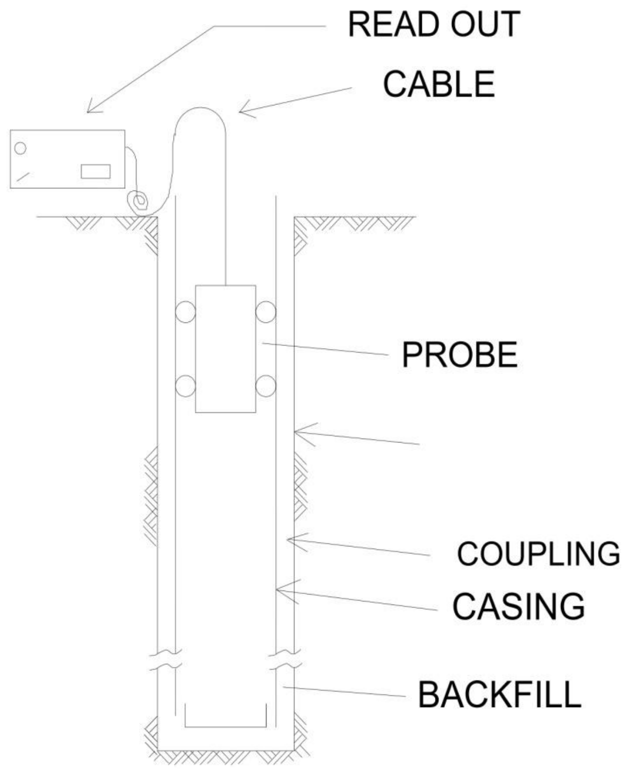


Figure E-10 INCLINOMETER

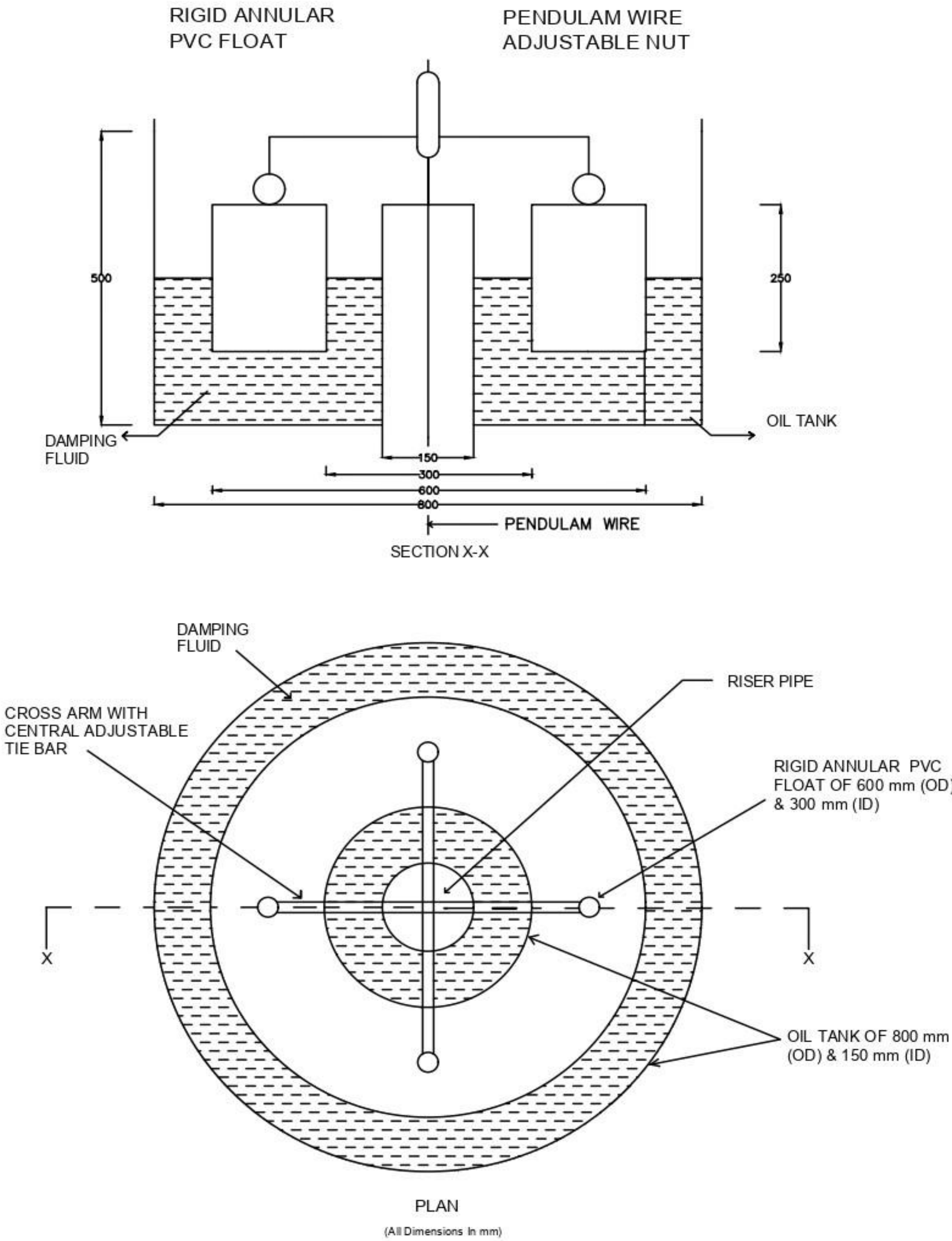
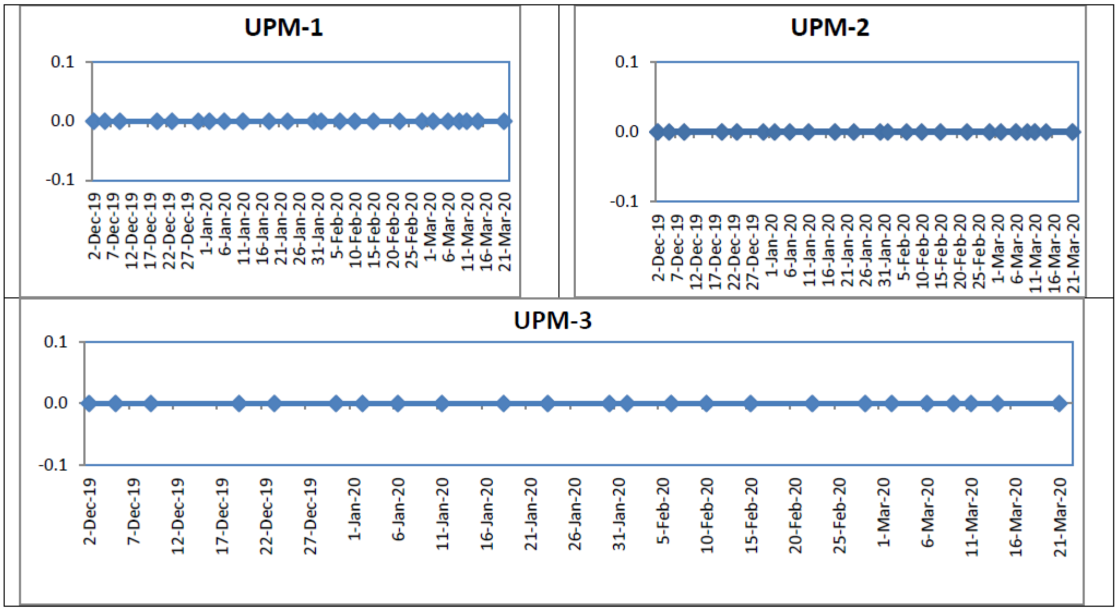


Figure E-11 INVERTED PLUMBLINE

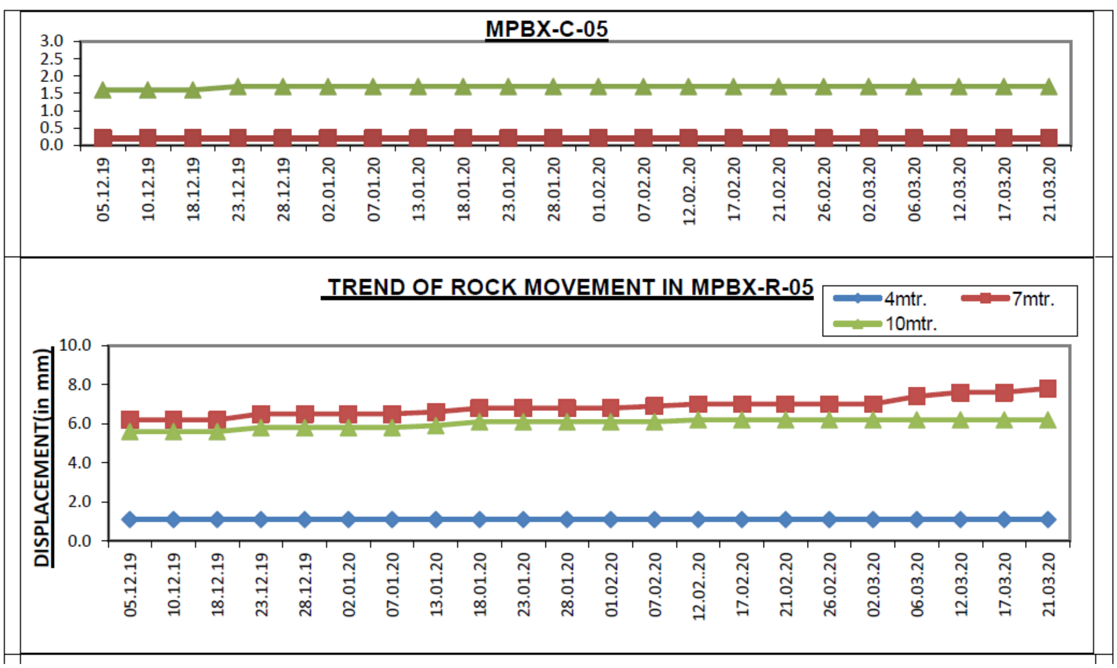
Annexure F

SAMPLE PLOTS OF INSTRUMENTATION DATA

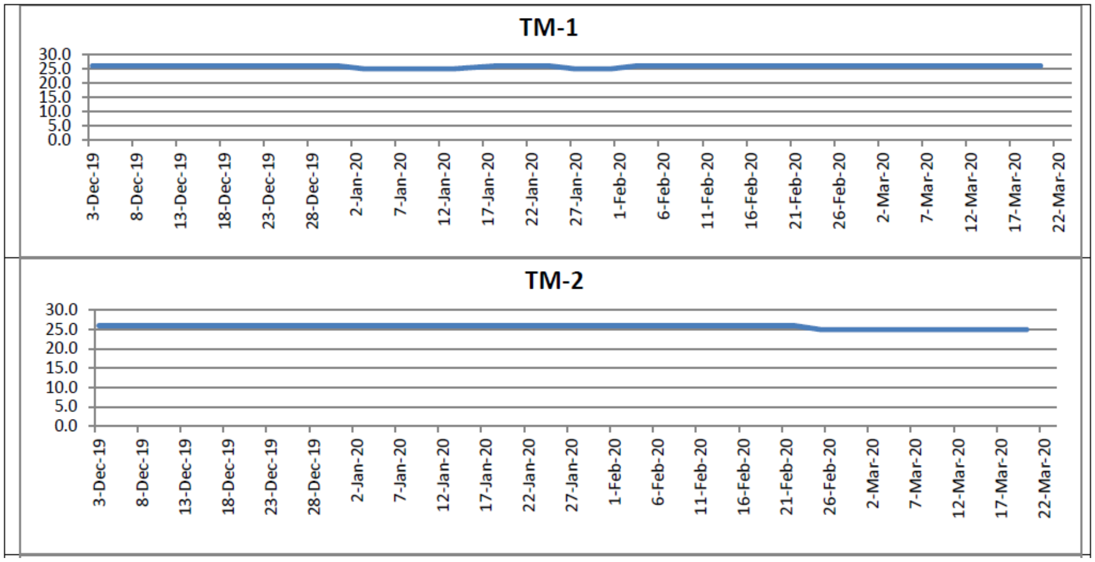
Uplift Pressure (in KSc) vs. Date plots



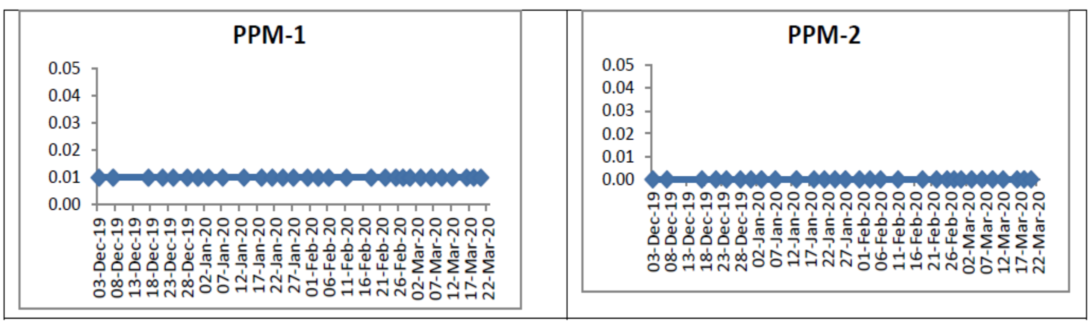
Displacement (in mm) vs. Date plots



Temperature (in ^{o}C) vs. Date plots



Water Pressure (in MPa) vs. Date plots



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