भारतीय मानक ब्यूरो
(उपभोक्ता मामले, खाद्य एवं सार्वजनिक वितरण मंत्रालय, भारत सरकार)
BUREAU OF INDIAN STANDARDS
(Ministry of Consumer Affairs, Food & Public Distribution, Govt. of India)

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व्यापक परिचालन मसौदा

हमारा संदर्भ : सीईडी 39 /टी - 3 **09 फरवरी 2024**

तकनीकी समिति : भूकंप इंजीनियरिंग अनुभागीय समिति , सीईडी 39

प्राप्तकर्ता :

1. **सिविल अभियांत्रिकी विभाग परिषद, सीईडीसी के सभी सदस्य**
2. **भूकंप इंजीनियरिंग अनुभागीय समिति, सीईडी 39 के सभी सदस्य**
3. **सीईडी 39 की उपसमितियों और अन्य कार्यदल के सभी सदस्य**
4. **रुचि रखने वाले अन्य निकाय।**

महोदय/महोदया,

निम्नलिखित मानक का मसौदा संलग्न हैं:

प्रलेख संख्या	शीर्षक
सीईडी 39(24823)WC	**बांध परियोजनाओं का भूकंप यंत्रीकरण का भारतीय मानक मसौदा (IS 4967 का पहला पुनराभ्यास) (आई सी एस संख्या : 91.120.25)**

कृपया इस मसौदे का अवलोकन करें और अपनी सम्मतियाँ यह बताते हुए भेजे कि यह मसौदा प्रकाशित हो तो इन पर अमल करने में आपको व्यवसाय अथवा कारोबार में क्या कठिनाइयां आ सकती हैं।

सम्मतियाँ भेजने की अंतिम तिथि: 25 मार्च 2024

सम्मति यदि कोई हो तो कृपया अधोहस्ताक्षरी को ई-मेल द्वारा ced39@bis.gov.in पर या उपरलिखित पते पर, संलग्न फोर्मेट में भेजें। सम्मतियाँ बीआईएस ई-गवर्नेंस पोर्टल, www.manakonline.in के माध्यम से ऑनलाइन भी भेजी जा सकती हैं।

यदि कोई सम्मति प्राप्त नहीं होती है अथवा सम्मति में केवल भाषा संबंधी त्रुटि हुई तो उपरोक्त प्रालेख को यथावत अंतिम रूप दे दिया जाएगा। यदि सम्मति तकनीकी प्रकृति की हुई तो विषय समिति के अध्यक्ष के परामर्श से अथवा उनकी इच्छा पर आगे की कार्यवाही के लिए विषय समिति को भेजे जाने के बाद प्रालेख को अंतिम रूप दे दिया जाएगा।

यह प्रालेख भारतीय मानक ब्यूरो की वेबसाइट www.bis.gov.in पर भी उपलब्ध हैं।

धन्यवाद।

भवदीय
ह/-
अरुण कुमार एस
वैज्ञानिक ई एवं प्रमुख
सिविल अभियांत्रिकी विभाग

संलग्न: उपरलिखित

भारतीय मानक ब्यूरो
(उपभोक्ता मामले, खाद्य एवं सार्वजनिक वितरण मंत्रालय, भारत सरकार)
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WIDE CIRCULATION DRAFT

Our Reference: CED 39/T-3 **09 February 2024**

TECHNICAL COMMITTEE: EARTHQUAKE ENGINEERING SECTIONAL COMMITTEE, CED 39

ADDRESSED TO:

1. All Members of Civil Engineering Division Council, CEDC
2. All Members of Earthquake Engineering Sectional Committee, CED 39
3. All Members of Subcommittees, Panels and Working Groups under CED 39
4. All others interested.

Dear Sir/Madam,

Please find enclosed the following draft:

Doc No.	Title
CED 39(24823)WC	**DRAFT INDIAN STANDARD** **EARTHQUAKE INSTRUMENTATION OF DAM PROJECTS** (*First Revision of* IS 4967) ICS 91.120.25

Kindly examine the attached draft and forward your views stating any difficulties which you are likely to experience in your business or profession, if this is finally adopted as National Standard.

Last Date for comments: 25 March 2024

Comments if any, may please be made in the enclosed format and emailed at ced39@bis.gov.in or sent at the above address. Additionally, comments may be sent online through the BIS e-governance portal, www.manakonline.in.

In case no comments are received or comments received are editorial, kindly permit us to presume your approval for the above document as finalized. However, in case of comments, technical in nature are received, then they may be finalized either in consultation with the Chairperson, Sectional Committee, or referred to the Sectional Committee for further necessary action if so desired by the Chairperson, Sectional Committee.

The document is also hosted on the BIS website www.bis.gov.in.

Thanking you,

Yours faithfully,

Sd/-

Arun Kumar S

Scientist 'E' & Head

Civil Engineering Department

Encl: As above

FORMAT FOR SENDING COMMENTS ON THE DOCUMENT

[Please use A4 size sheet of paper only and type within fields indicated. Comments on each clause/sub-clause/ table/figure, etc, be stated on a fresh row. Information/comments should include reasons for comments, technical references and suggestions for modified wordings of the clause. **Comments through e-mail to ced39@bis.gov.in shall be appreciated**.]

Doc. No.: CED 39()WC

BIS Letter Ref: CED 39/T-3

Title: Draft Indian Standard Earthquake Instrumentation Of Dam Projects

Last date of comments: 25 March 2024

Name of the Commentator/ Organization: _____

Sl No.	Clause/ Para/ Table/ Figure No. commented	Type of Comment (General/ Technical/ Editorial)	Comments/ Modified Wordings	Justification of Proposed Change

NOTE- Kindly insert more rows as necessary for each clause/table, etc

BUREAU OF INDIAN STANDARDS

DRAFT STANDARD FOR COMMENTS ONLY

(Not to be reproduced without the permission of BIS or used as an Indian Standard)

Draft Indian Standard

EARTHQUAKE INSTRUMENTATION OF DAM PROJECTS

(*First revision of IS 4967*)

ICS 91.120.25

Earthquake Engineering Sectional Committee, CED 39	**Last Date for Comments: 25 March 2024**

FOREWORD

(*Formal clauses to be added after finalization*)

Earthquake instrumentation required for near real-time monitoring of dam projects will help in the earthquake safety assessment of the dams through the characterisation of:

a) Earthquake sources around the dam projects before and after the construction of the structures,
b) Earthquake ground motion, structural responses of the structures, and verification of design parameters by the structural response measured during earthquake ground shaking, and
c) Reservoir triggered seismicity.

This standard contains general provisions on earthquake instrumentation applicable to Dam projects.

This first revision is based on significant experience gained over the last five decades in the subject of earthquake monitoring of the ground and built structures, especially in the domain of earthquake instrumentation. In 2022, the Committee decided to revise the provisions to keep abreast with rapid developments in instrumentation and extensive research carried out in earthquake-resistant design of proposed large projects and earthquake safety assessment of existing large projects.

In this revision, the following changes have been included:

1) The scope has been expanded to include instrumentation to capture strong earthquake shaking of:

    a) the ground at and adjoining the dam sites, and
    b) the buildings and critical structures associated with dams.

2) Guidance is provided on parameters of earthquake shaking to be captured, and on the selection of type, detailed specifications, location, and number of instruments.

3) Emphasis is laid on database management and processing protocols.
4) The provisions on dam projects have been extended to include:

    a) Measurements needed,
    b) Sensors to be used,
    c) Digital Data System required,
    d) Installation procedure to be adopted,
    e) Maintenance to be complied with, and
    f) Processing and dissemination of data to be agreed upon.

In the formulation of this standard, effort has been made to coordinate with standards and practices prevailing in different countries in addition to relating it to the practices in the field in this country.

To decide whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2: 2022 ‘Rules for rounding off numerical values (*second revision*). The number of significant places retained in the rounded-off value should be the same as that of the specified value in this standard.

BUREAU OF INDIAN STANDARDS

DRAFT STANDARD FOR COMMENTS ONLY

Draft Indian Standard

EARTHQUAKE INSTRUMENTATION OF DAM PROJECTS

(*First revision of IS 4967*)

ICS 91.120.25

1 SCOPE

1.1 This standard deals primarily with recommendations for instrumentation required for near real-time monitoring of dams and the associated built structures that are part of existing dam projects towards realistic earthquake response estimation of structures, earthquake hazard monitoring, and defining earthquake design criteria for structures to be built in future in that region.

1.2 The purpose of this standard is to assist in:

a) characterising earthquake sources (namely magnitude, hypocentral location, and source mechanism) in the geological neighbourhood of existing dams;
b) characterising earthquake ground motions and structural response of built structures at dam sites;
c) characterising reservoir-triggered seismicity which exhibits this behavior;
d) calibrating the analytical tools that form the input during the design phase for earthquake analysis of the dams, towards tuning the analytical models to match the dynamic characteristics of the dams; and
e) capturing damages in the dams during a likely future earthquake.

1.3 The provisions of this standard may be adopted in dam projects, after suitably customizing to meet the needs of such projects. In such cases, the requirements specified by this standard shall be taken as at least the minimum that should be met with.

2 REFERENCES

The standards listed below contain provisions, which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

IS No.	*Title*
CED39 (22343)WC	Criteria for earthquake-resistant design of structures Part 1 General Provisions
IS 13920 : 2016	Ductile design and detailing of Reinforced Concrete structures subjected to seismic forces – Code of Practice (*first revision*)
IS 18168 : 2023	Earthquake resistant design and detailing of Steel Buildings

3 TERMINOLOGY

For the purpose of this standard, the definitions given below shall be applicable.

3.1 Seismograph — An instrument comprising a sensor and recording device to record ground motions during the earthquake.

3.2 Broad Band Velocity Seismometer — Three-component sensors capable of sensing ground motions over a wide range of frequencies, hence the term 'broadband'. Modern, feedback electronics lead to the housing of three-component, broadband sensors in a single case, and are portable and can be deployed at short notice to record weak motions from micro, regional, and teleseismic earthquakes, as well as ambient noise.

3.3 Accelerometers — Strong-motion sensors are accelerometers designed to measure the large amplitude, high-frequency seismic waves typical to large magnitude local earthquakes. These seismic waves result in the strong ground motion felt during a large earthquake.

3.4 Data Acquisition System (DAS) – Signal conditioners consisting of pre-amplifiers, analog to digital (A/D) converters, time signal receivers, on-site data storage units, telemetry interface, and state of health information to both local and remoter users.

3.5 GPS — Global Positioning Systems (GPS) are all-weather systems which are based on satellite constellations which allow world-wide terrestrial, maritime, and aerial navigation and location determination, using passive receivers that triangulate a three-dimensional position based on radio signals received from a minimum of four satellites.

3.6 Time Series Data — Continuous seismological data recordings (velocity and accelerogram) from a number of seismological stations.

3.7 Metadata — Information about station location, recording instrument characteristics, and data quality.

4 ABBREVIATIONS

Unless otherwise stated, the abbreviations specified below shall be used.

Abbreviation Used	*Description*
DAS	Data Acquisition System
RMS	Root Mean Square
GPS	Global Positioning System
PGA	Peak Ground Acceleration
PGV	Peak Ground Velocity
PGD	Peak Ground Displacement
CRS	Central Receiving Station
OEM	Original Equipment Manufacturer
SEED	Standard for the Exchange of Earthquake Data

5 PRINCIPLES OF EARTHQUAKE MONITORING

Earthquake monitoring of dams requires appropriate instruments of required sensitivity and range for recording to be placed at the appropriate location to capture the earthquake ground motion and earthquake responses of dams.

5.1 Parameters

The parameters to be derived from earthquake instrumentation are:

a) Earthquake source parameters, namely the hypocentral location (latitude, longitude and focal depth), origin time of the earthquake occurrence, focal mechanism (strike slip, normal and thrust) and the magnitude of the earthquake;
b) Weak motion data of peak particle velocity;
c) Ground motion accelerations in horizontal and vertical directions; and
d) Global Response Parameters at specific locations of the dams.

5.2 Instrument Location

The work required to instrument large projects is humongous. Hence, the effort of instrumentation shall be undertaken in a phased manner, starting from Seismic Zones VI, V and IV.

The location of sensor in each large project shall be specified in the corresponding sections.

5.3 Instrument Selection

Two sets of earthquake motions shall be measured, namely:

a) Those related to the ground, and

b) Those related to the structures.

The former is of three types, namely weak ground motions (from events at teleseismic distances), far field ground motions and near field ground motions.

The selection of instruments shall depend on the parameter to be measured. Table 1 gives the instruments to be used for different parameters to be measured such as PGA ± 2g, PGV ± 2 m/s and PGD ± 2m.

Table 1 Instruments Needed to Measure Different Parameters
(*Clause* 4.3)

Sl No.	Parameter to be Measured	Instrument Needed
(1)	(2)	(3)
Ground Motion		
1. Teleseismic Ground Motions		
	Velocity of the ground	Broad-band seismometer
2. Far Field Ground Motions		
	Velocity of the ground	Broad-band seismometer
3. Near Field Ground Motions		
a)	Acceleration	Strong Motion Accelerograph
b)	Displacement	Global Positioning System Device
Structure Response		
1	Acceleration	Strong Motion Accelerograph

5.4 Database Management

The large volume of earthquake measurement data shall be archived and disseminated to appropriate stakeholders. When doing so, the earthquake parameters specified in **5.1** shall be provided in a standard format.

5.5 Processing Protocols

The internationally acceptable global protocols shall be adopted for measurement, archiving and dissemination of data. A summary of the protocols required are presented in **Table 2**.

Table 2 Protocols Required for Processing Ground Motions and Structural Responses
(*Clause* 5.5)

Sl No.	Requirement	Protocol
(1)	(2)	(3)
Ground Motion		
1	Data Acquisition	Standard Protocol by *Global Agencies*
2	Data Archiving	Standard Protocol by: a) National Center for Seismology, Ministry of Earth Sciences, Government of India, and b) *Global Agencies*
3	Data Processing	National Center for Seismology, Ministry of Earth Sciences, Government of India a) Correction procedure should not remove the near fault characterisation
4	Data Dissemination	
Structure Response		
1	Acceleration	Strong Motion Accelerograph

C5. Principles of Earthquake Monitoring

Seismic monitoring is the foundation upon which all earthquake mitigation practices are built. Seismic monitoring is also necessary for hazard warning, assessment, and research. Seismic monitoring systems consist of sensors, recorders, and data analysis centres. Most of the existing systems monitor either weak seismic motions or strong ground shaking.

Seismological monitoring systems record displacements generated by seismological (elastic) waves, which propagate through the Earth and produce ground motions either due to volcanic eruptions, quarry blasts, sonic booms, mine collapses, meteorite impacts, and underground nuclear testing. The seismological monitoring is comprised of (1) a sensor (seismometer) that converts vibratory ground motion into an electric signal, (2) a local recorder or a communication network that transmits this signal to a data center, and (3) analysis at the center that combines the seismograms transmitted from many seismometers for estimating hypo-central location, magnitude, peak acceleration, and other parameters that characterize the source and event nature. The state-of-the-art earthquake monitoring systems are of two types, weak and strong motion. Weak-motion monitoring systems use very sensitive sensors that can record weak vibrations in frequencies ranging between 0.01 Hz to 50 Hz such as local and tele seismic earthquakes whose magnitudes vary between micro to large. The products obtained from earthquake networks are the earthquake catalogues which provide the location and magnitude of seismic events within the region covered by the sensor network over a given period of time. Strong-motion monitoring systems use sensors (called accelerometers) and record strong ground motion which, potentially damage the man-made structures due to intense ground shaking. Strong motion is generally associated with earthquakes greater than about magnitude 4 or 5. Strong-motion recordings provide fundamental data for engineering design and construction practices and for seismic design criteria for building codes. The primary data and the inferences from accelerograms of strong shaking and allow in

proposing empirical relationships showing the attenuation of strong ground shaking with increasing distance from the source.

C5.1 Parameters

The earthquake parameters which include in estimating the hypocentral parameters, Magnitude and ground motion acceleration values and the by products are the response spectra of the free site and the structure under investigation.

(a) Hypocentral Parameters

The seismological network designed at a large project requires at least five instruments encompassing the site under surveillance for seismicity. The seismological instruments would include the velocity meters. This is mandatory since we need to estimate four parameters which include latitude, longitude, focal depth and origin time.

(b) Magnitude

In the magnitude estimation of the earthquakes the local earthquake network suffices since the broadband velocity seismometers are considered while designing the network.

(c) Acceleration and Response Spectra

Strong-motion measurements located in the free field define the expected free-field ground motion (that is, shaking of the ground on which structures are built). In turn this forms the input in the performance evaluation of structures and systems.

The measurements obtained for large structures shall enable a complete analysis of the structural response to strong ground shaking. These measurements include constitutive properties of soils, ground displacements, transient stresses and strains in structural elements, and hydrodynamic pressures.

C5.2 Instrument Location

The total number of sensors to be installed on a structure, their locations, the distance between instruments, the algorithms in use and processing should be appropriately determined beforehand to avoid data overloads which includes number of measurements, various levels of accuracy of different data sets and the technical requirements.

C5.3 Instrument Selection

The state of art instrumentation is selected and is applicable for all types of dams; existing and future one.

C5.4 Database Management

The data base management involves perpetually archiving continuous time series data, quality control of waveform and metadata. The wave form data shall be recorded as per the international practices such as seed, mini seed. The data shall be recorded in the said formats by most of the presently available seismological instruments.

6 INSTRUMENTATION OF DAMS

The provisions of this clause shall be applicable to all types of dams, embankments and appurtenant structures.

C6. INSTRUMENTATION OF DAMS

It emphasis on understanding how strong shaking propagates and how does the Earth respond to strong shaking and the way it influences the design, performance of structures and critical facilities within the dam. Measurements of site-specific ground motion and the site response helps in the prediction of future free-field ground motion at a specific site and its influence on the dam structure. To assess the dam safety, strong motion measurements are required in the dam and its abutment structures for monitoring the response of the dam. The modal characteristics of the vibration of the dam become an important criterion. The fundamental mode and other first few modes of vibration of the dam structure are generally in longitudinal direction of the dam. For obtaining the above parameters it is necessary to have appropriate seismological network is installed.

Seismological instrumentation which includes seismometers and accelerometers are to be established at the project site for evaluation of seismic parameters at large dams. The location of seismometers should be installed on the firm rock or suitable ground is available for founding the seismological piers. The seismometer and accelerometer are to be located at site which shall not be affected by ambient noise vibrations caused by powerhouse operations, etc. Strong motion accelerographs and structural response recorders are to be installed at the base of the dam (in a recess provided in the foundation gallery) and at the top of the dam. The location may be suitably selected to avoid the background seismic noise created due to the vibration originating from the appurtenant works 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.

6.1 Measurements Needed

The main reasons for seismic monitoring of dams are:

a) Precisely defining the seismicity of the region, that is, the exact location of earthquake epicentres and their depths,
b) Defining Magnitude, Frequency characteristics and source mechanism,
c) Providing data on the dynamic behaviour of the dam body for the purpose of objective evaluation of its functioning immediately after the earthquake occurrence, and

d) Verifying design parameters by the actual behaviour of the dam body during strong ground shaking.

6.1.1 *Free Field Motion*

Frequency, amplitude and duration of the strong motion are strongly influenced by the morphology of the canyon, local geological conditions, earthquake rupture propagation and mechanism of the earthquake.

At least three accelerographs need to be installed at different locations (such as at the bottom of the canyon and others on the top of the canyon) to discriminate the variation in the ground motion due to the geo-morphological conditions.

6.1.2 *Abutment Motion*

Strong motion data of the abutment structures with the canyon shall provide information about relative motion, if any, between abutments and dam structure during an earthquake.

6.1.3 *Dam Responses*

When capturing the dam response, the modal characteristics of the vibration of the dam become an important criterion. The fundamental mode and the higher modes of vibration of the dam structure are obtained through processing of the strong motion accelerogram data.

6.2 Sensors

Earthquake instruments shall be classified into two kinds, namely the broadband velocity seismometers and strong motion accelerographs. The data from these sensors are recorded onto a Digital Acquisition System.

a) *Velocity Meter*
The Broadband Velocity seismometer is a tri-axial, force balanced, broadband velocity transducer with electronic feedback and axial accuracy better than 1º.

b) *Accelerometer*
An accelerometer is an electromechanical tri-axial device, which records accelerations along 3 directions.

c) *Displacement Meter*
A displacement meter is a *global positioning system*, tri-axial device that records displacements along 3 plan directions.

6.2.1 *Specifications*

a) Broadband Seismographs

Broadband velocity seismometer and data acquisition system are an integral part of the system to record ground motion velocity with time. The instruments of the present

generation are digital systems with the sensors working on the principle of force feedback system. The minimum specifications of the sensors required to be deployed shall be as specified hereunder.

The sensor shall have the following capabilities:

i) *Tri-axial*: (Vertical, North-South, East-West), Force balanced, broadband velocity transducer with electronic feedback and axial accuracy better than 1°, for surface fault deployment.
ii) *Frequency response:* Flat response (within +/- 3 dB) to ground velocity in the range of 120 sec to 50 Hz.
iii) *Dynamic range*: ≥ 135 dB
iv) *Full-scale Output voltage:* ± 20V
v) *Damping*: 0.7 times of critical damping
vi) *Output Sensitivity* ≥ 1500 V/m/sec
vii) *Linearity*: Less than ± 1 percent of full-scale
viii) *Mass Centering*: An option to perform the mass centering through a motorized method either, by an external command given locally or remotely. The temperature range for which no centering is required shall not exceed ± 20°C.
ix) *Frequency Response Curve*: The frequency response curve of the unit along with information regarding the transfer function including poles, zeros, and normalization factor provided by the manufacturer (for each sensor as per the serial number) shall be over the range of 120 sec to 50 Hz;
x) *Noise*: Noise response shall be below the USGS New Low Noise Model in the frequency range of 120 sec to 50 Hz. Test reports of the sensor noise over the full pass band shall be provided by the manufacturer;
xi) *Levelling*: Bubble level indicator shall be provided for leveling the transducer;
xii) *Orientation:* Suitable marks shall be provided to indicate the direction of the relative orientation of the transducer;
xiii) *Mass Locking:* Automatic or manual mass locking and safety mechanism shall be provided to be activated during transportation;
xiv) *Enclosure*: The sensor should be placed in a shock and water-resistant enclosure; and
xv) *Humidity*: It shall be functional up to 100% RH.
xvi) *Power*: Input power range 9 – 18 V DC.
xvii) *Power consumption* ≤ 1.5 watts at 12 V DC.
xviii) Reverse voltage protection and Over voltage protection with Built-in Lightning protection.
xix) An airtight thermal insulation cover from OEM shall be provided.
xx) A rugged field carry case for a seismometer from OEM shall be provided.
xxi) Detailed user manual/data sheets/calibration data sheet to be provided

The test reports of the quoted model of the seismometer from the internationally recognized standard test laboratories like USGS Albuquerque seismological laboratory/IRIS shall be attached along with technical bid documents.

b) Strong Motion Accelerographs

These are triaxial, orthogonally oriented, force balanced transducers (one vertical and two horizontal) along with the data acquisition system in a single sealed unit.

The sensor shall have the following capabilities:

i) *Full Scale Range*: User (Software) selectable ± 4g, ± 2g, and ± 1g;
ii) *Frequency response*: Flat (within ±3 dB) to ground acceleration in the range of 0 Hz to 200 Hz;
iii) *Dynamic Range*: 150 dB or more;
iv) *Linearity*: < 1000 µg/g^2
v) *Hysteresis*: Less than 0.1 percent of full scale;
vi) *Cross-axis sensitivity*: Less than 0.5 percent of full scale;
vii) *Orientation:* A suitable mark shall be placed to indicate the direction of relative orientation of the transducer;
viii) *Calibration Facility*: It should be accessible for calibration from the Data Acquisition System (DAS) locally or remotely from central recording station through DAS;
ix) *Recording Mode:* It should have continuous and triggered capabilities;
x) *Triggering:* The DAS should be capable of recording the acceleration data in the STA/LTA ratio trigger, threshold trigger and time window options;
xi) *Trigger Selection**:*** It should permit independent selection for each channel;
xii) *Threshold Trigger:* It should be user selectable from 0.01 percent to 100 percent of the full scale;
xiii) *Pre-event Recording Length**:*** It should be user selectable up to 30 s or more; and
xiv) *Post-event Length:* It should be user selectable up to 90 sec or more.

Detailed user manual, data sheets and calibration data sheet of the accelerometer should be provided.

6.2.2 *Location and Number*

Strong motion accelerographs should be installed at least at the base of the dam in a recess provided in the foundation gallery and at the top of the dam; if intermediate galleries are present. The location shall be such that the background noise created due to the vibration originating from the appurtenant works of the dam is avoided. 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 (and at intermediate heights) are expected to provide information about response of the dam to the earthquake.

The minimum number and comprehensiveness of the broadband seismographs required for monitoring the local earthquake activity, on the basis of dam height, is given as below:

a) H < 30 m : 1 Tri-axial broad band seismograph
b) 30 m < H < 60 m : 3 Tri-axial broad band seismographs

c) 60 m < *H* <100 m : 5 Tri-axial broad band seismographs in a radius of 50 km
d) *H* > 100 m : To be decided by the Competent Authority

In regions where large magnitude earthquakes occurred in the past, the GPS instruments (for recording the displacements in the near field) shall be co-located with broadband seismographs and strong motion accelerographs.

a) Concrete Dams

A maximum of twelve accelerographs are proposed for installation, the layout of which shall be:

i) Crest : 4
ii) Abutment : 2
iii) Toe : 2
iv) Heel : 2
v) At half the distance between crest and toe : 1
vi) At half the distance between crest and Heel : 1

A typical arrangement of seismographs in concrete gravity and arch dams is represented in Fig. 1, 2 and 3.

(b) Earth Dams and Embankments

At least a minimum of five accelerographs shall be installed, the layout of which shall be:

i) At the crest : 1
ii) Abutments : 2
iii) At the toe : 1
iv) Half way between the toe and the crest : 1

6.2.3 *Specifications*

The specifications of the sensors shall be as per Table 3**.**

Table 3 Specifications of Broad-band Seismographs and Strong Motion Accelerographs
(*Clause* 6.2.3)

Sl No.	**Feature**	**Instrument**	
		Broad-Band Seismographs	*Strong Motion Accelerographs*
(1)	(2)	(3)	(4)
1)	Range	Flat Frequency Response (within +/- 3 dB) to ground velocity	Flat Frequency Response (within +/- 3 dB) to ground velocity in

		in the range of 0.008 Hz (120 s) to 50 Hz	the range of 0 Hz to 200 Hz
2)	**Resolution**		
a)	Dynamic range	≥ 135 dB at 5 Hz	≥ 150 dB at 3-30 Hz
b)	Output voltage	± 20 V	± 2.5 V
c)	Damping	70 percent of critical	NA
d)	Linearity	Less than ± 1 percent of full-scale	< 1 000 µg/g^2
e)	Generator constant	≥ 1 200 Volts/(m/sec)	NA
3)	**Sensitivity**	≥ 1 500 V/m/sec	24-bit digital output
			Selectable ± 4g and ± 2g

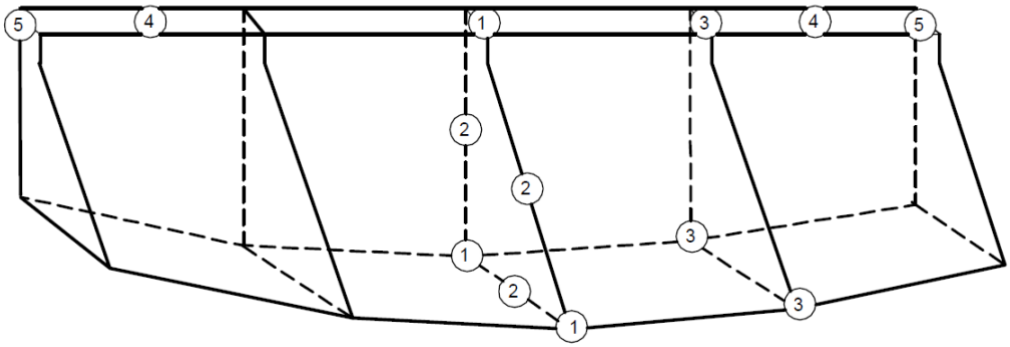

FIG. 1 COMPREHENSIVE SCHEME OF STRONG MOTION ACCELEROGRAPHS FOR GRAVITY DAMS

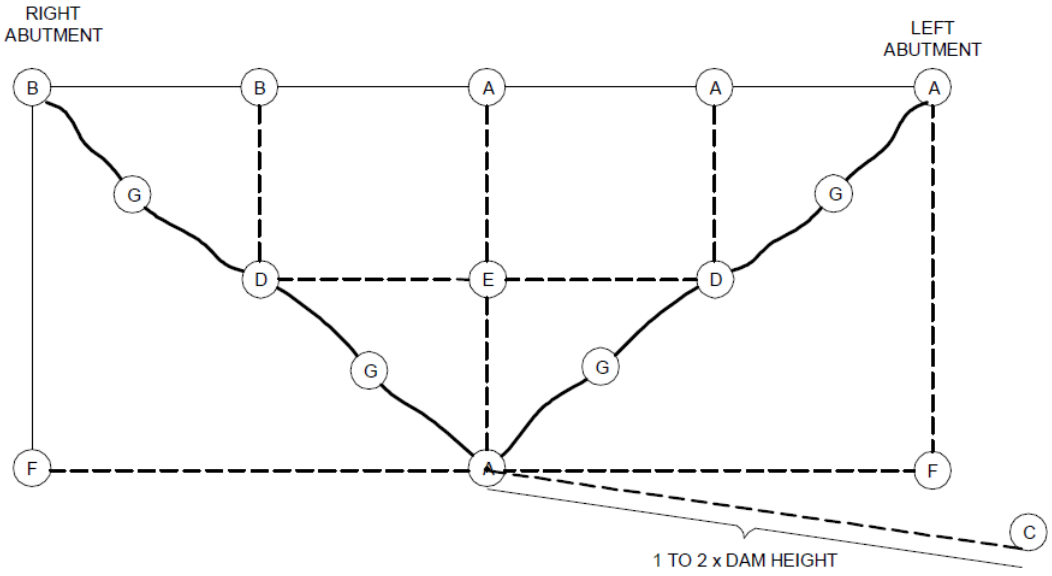

FIG. 2 ACCELEROGRAPH ARRAYS FOR ARCH DAMS (DOWNSTREAM VIEW)

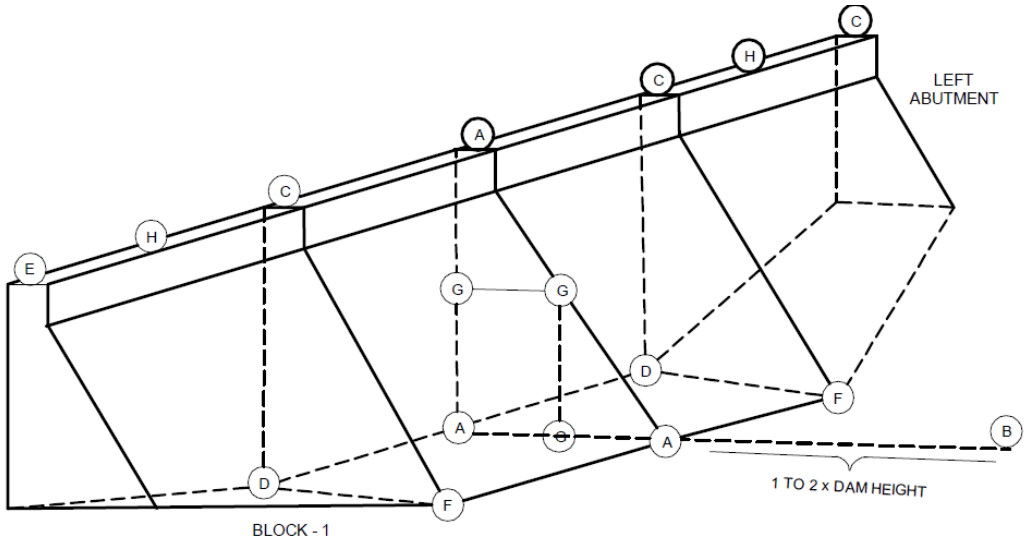

FIG. 3 ACCELEROGRAPH ARRAYS FOR GRAVITY DAMS

6.3 Digital Data System

The preamplifiers shall be capable of adjusting the analog output of the sensor, match impedance and adjusting gain level on the input to the A/D converter. These digitizers shall be power efficient and designed for rugged, harsh environments.

6.3.1 *Resolution*

The salient specifications are:

a) *Number of Channels* 3

b) *Digitizers*	3 independent 24-bit digitizers, 1 per channel
c) *Dynamic Range*	≥ 135 dB @ 100 samples per second
d) *Input Full-Scale Range*	Sensor output with full scale at ± 20 V (40 Vpp)
e) *Common Mode Rejection Ratio*	> 70 dB
f) *Channel to Channel Skew*	Zero (simultaneous sampling of all the channels)

6.3.2 *Noise Level*

The overall system noise shall not be more than 2-3 counts of 24-bit system on a Root Mean Squared basis in the frequency range of 120 sec to 50 Hz.

6.3.3 *Sensor Controller*

The sensor controller shall have the facility to calibrate, mass position monitoring, and mass centering on command of the broadband seismometer.

a) Resolution

A status indicator (in-built or external) for indicating the power, data acquisition and GPS status shall be provided. The DAS shall be capable of:

i) Recording on the local storage media as well as support real-time data telemetry to a central site through VSAT telemetry network simultaneously; and
ii) Retrieving the old data in the storage media from Central Recording Station manually through VSAT network.

b) GPS Receiver Clock

It shall have the following capabilities:

i) Timing accuracy of ±10 µsec or better when GPS is locked;
ii) Free running accuracy 0.1ppm over a wide range of temperature;
iii) Record of GPS status information;
iv) DAS-GPS cable length of at least 20 meters with end connectors; and
v) Rust proof GPS mounting rod and accessories**.**

c) Power Requirements

The following shall be the features:

i) Supply voltage 9-18V DC,
ii) Power consumption < 1.5 watts, 12V DC for recording 3 channels at 100 samples per second, and continuous mode data acquisition,
iii) Supply power isolated from the signal ground;
iv) Reverse voltage protection;

v) Low battery voltage protection;
vi) DAS power cable of at least 3 m length;
vii) Resumption of data acquisition automatically when power is restored after disruption;
viii) Operating Temperature - 20° to 60°C;
ix) Humidity resistance up to 100 percent RH;
x) DAS and GPS units enclosed in weather and shock resistant sealed enclosures with lightning protection; and

Detailed user manual and data sheet shall be provided.

d) Sampling

The sampling rate shall be:

i) User selectable up to 1 000 samples per second/channel in different data streams (at least 2 or more);
ii) Simultaneous recording at different sampling rates in different streams (at least 2 or more), both in continuous and trigger modes; and
iii) Trigger parameters should be user selectable.

6.3.4 *Recording System*

The data recording and storage system shall have the following features:

a) RAM of 8 MB or more;
b) User removable recording media of capacity 32 GB or more;
c) Hot-swappable recording media;
d) Standard seismic data recording format compatible with Windows and Linux platforms with proven compression technique;
e) Capability to record on the Stand-alone Mode on a local storage media as well as support real-time data telemetry to a central site through VSAT telemetry network simultaneously; and
f) Internet or VSAT-based recording with:

i) *Communication Ports*

i) USB and or serial port for Ethernet connectivity to a local terminal for parameter setting and data downloading; and
ii) Ethernet port (10/100 Base - T) supporting TCP/IP Protocol; and

ii) *DAS Firmware Features*

i) Web browsing support/ communication over TCP/IP;
ii) Support off-the-shelf communication equipment;
iii) Extensive error correction;
iv) Status indicator (in-built or external) for indicating the power, data acquisition, and GPS status should be provided; and
v) DAS with the facility to retrieve old data manually from the storage media of the Central Recording Station through the VSAT network.

g) Connectivity to Central Monitoring Station with built-in modem support for full duplex communication between the digitizer and terminal field station, and Central Receiving Station (CRS) Triggered or continuous data transmission.

6.4 Installation

The earthquake instruments shall be installed to record free field ground motion, abutment motion and dam response.

6.4.1 *Free Field Motion*

The instruments shall be located near both abutments at the toe of the dam. But, the need to install instruments at suitable distances beyond any significant influence of the dam on the recorded ground motion shall be determined by an expert group constituted by the Competent Authority. Ambient noise survey shall be carried out for ascertaining the back ground noise due to spillway discharge or hydro power stations for establishing the seismological locations.

6.4.2 *Abutment Motion*

The instruments shall be located at the downstream toe and at the abutments as close to the dam as possible. They shall be placed on concrete piers firmly secured to the underlying rock or surface material, which is protected by an earthquake resistant enclosure. But, finding suitable locations at the toe may be difficult owing to water conditions, and at the abutments owing to restricted access due to topographic conditions.

6.4.3 *Dam Response*

One or two instruments shall be installed on the crest of both earth and concrete dams.

The locations shall be:

a) Where maximum deformation is expected to be strong motion during earthquake shaking; and
b) At about one-third of the crest length from an abutment.

6.5 Maintenance

The instruments shall be maintained every six months to capture the state of health of the dam for its continuous operation.

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Annex A

(Committee Composition will be added after finalization)