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Smart community infrastructures — Disaster risk reduction — Guidance for implementing seismometer systems

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Foreword

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This document was prepared by Technical Committee ISO/TC 268, *Sustainable cities and communities*, Subcommittee SC 1, *Smart community infrastructures*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Earthquakes are one of the most devastating of all natural hazards. To achieve the goal set by the Sendai Framework for Disaster Risk Reduction 2015–2030,[19] it is necessary for relevant stakeholders in communities to prevent and reduce damage caused by earthquakes and maintain the level of services and quality of life in the community after an earthquake. Effective use of a seismometer system contributes to these objectives by enabling more informed emergency responses. Data from seismometer systems also helps to improve understanding and modelling of ground motion and structural behaviour, leading to improved seismic design regulations and improved seismic risk modelling.

In some seismically active countries, the damage caused by earthquakes has also been mitigated by installing appropriate seismometers and by effectively utilizing the data obtained. These data can be utilized for:

— land use control;

— the structural design of buildings and other facilities;

— emergency responses;

— evacuation guidance;

The data also help organizations to develop business continuity plans to help them to respond, recover and return to a pre-defined level of operation following the disruption.

However, the effectiveness of seismometer systems as one of the tools for seismic risk reduction has not been recognized globally due to a lack of systematic knowledge sharing. In countries or regions with rapid urbanization and significant earthquake risk, the lack of knowledge has resulted in the underutilization of seismometer systems. This makes the communities in these places less resilient.

This document aims to assist relevant stakeholders of communities, such as various levels of governments, planners, developers and operators, in optimizing their investment in urban development by deploying and utilizing seismometer systems as a tool for the disaster risk reduction of earthquakes. This document also describes a categorization of the purposes of seismometer systems for achieving disaster risk reduction, as well as the specifications of seismometer systems required for this specific purpose, as part of the smart community infrastructures described in ISO/TR 6030.

Analysis of the data obtained from seismometer systems provides information for managing risk and reducing the impact on people, organizations, infrastructures and livelihoods. It also provides information for planning preventive measures and emergency responses after an earthquake. For these reasons, effective utilization of data will enable communities to enhance their resilience to earthquakes.

Smart community infrastructures — Disaster risk reduction — Guidance for implementing seismometer systems

1 Scope

This document provides guidance for developing, implementing and maintaining seismometer systems as a part of the infrastructure for disaster risk reduction in smart communities. The seismometer systems in this document can be used for the observation of seismic activity, such as earthquakes, micro-seismic motion and volcanic tremors, especially in seismically active areas.

This document gives examples of how different types of seismometers can fulfil the needs and expectations of users and help planners, developers and community operators to effectively use seismometers and related data for disaster risk reduction.

This document is not applicable to the following:

— drop-ball type and pendulum type seismometers;

— how to design and develop seismometer systems (e.g. seismometers installed in railway systems).

The features of the seismometer systems in this document are not intended for the measurement of vibrations caused by landslides.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
hazard map
map developed to illuminate areas that are affected or vulnerable to a particular hazard (e.g. earthquakes, landslides, rockslides)

[SOURCE: ISO 37123:2019, 3.4]

3.2
earthquake focus
point inside the Earth where an earthquake originates, the fault rupture starts, and the seismic waves are generated

3.3
seismic intensity
degree of ground shaking at a given location, resulting from an earthquake

Note 1 to entry: The criteria for seismic intensity levels vary from country to country.

3.4
magnitude
number that characterizes the relative size of an earthquake

3.5
disaster
situation where widespread human, material, economic or environmental losses have occurred that exceeded the ability of the affected organization, community or society to respond and recover using its own resources

[SOURCE: ISO 22300:2021, 3.1.73]

3.6
P-wave
primary wave
elastic body wave in which the particle motion is in the direction of propagation

[SOURCE: ISO 19901-10:2021, 3.73]

4 Value, purpose and structure of the system

4.1 General

Seismometer systems should be selected according to their purpose and specifications for data acquisition (see 4.3 and 4.4). When developing and implementing seismometer systems, planners, developers and operators of communities should define the purpose and specifications for data acquisition and the structure of the system.

NOTE   A flowchart that can be used for determining the appropriate seismometer systems for specific purposes is provided in Annex A.

4.2 Value of utilizing seismometer systems

Examples of values achieved by effective use of seismometer systems are as follows:

a) from the perspective of stakeholders:

  1) reducing negative consequences and protecting lives, property, and the environment;

  2) recovering quickly from damage;

  3) meeting stakeholder expectations;

  4) taking quick protective actions following earthquakes;

b) from the perspective of community operations:

  1) improving the ability to maintain functions immediately after an earthquake and other seismic activity;

  2) taking proactive actions in an effective and efficient manner;

  3) fostering communities that are resilient, sustainable, liveable and smarter;

  4) providing an effective response strategy to emergencies and disasters;

c) from the economic perspective:

  1) reducing legal and financial burdens;

    2) reducing costs incurred by earthquakes;

d) from the business perspective:

    1) strengthening resilience;

    2) maintaining and improving reputation and credibility;

    3) strengthening sustainability;

e) for research and the professional community:

    1) improving the understanding of natural phenomena (e.g. earthquakes and volcanos);

    2) improving the understanding of vibrations on the ground and in structures due to natural phenomena (e.g. earthquakes and volcanos);

    3) improving design regulations and structural design.

By effectively utilizing seismometer systems, planners, developers and operators of communities can contribute to achieving the United Nations Sustainable Development Goals 3, 8, 9 and 11.

4.3 Purpose of use

Planners, developers and operators of communities should define the purposes for using seismometer systems. Examples of purposes include:

— assessing the exposure to hazards in the area;

— early detection and warning;

— evacuation alerts;

— controlling devices and systems.

Further details on the purposes of use are described in 6.1 and 6.2.

4.4 Data specifications

Seismometer data is time-series data for vibrations. The specifications for data acquisition should include:

— variables (e.g. acceleration, velocity and displacement);

— accuracy of location and time;

— real-time acquisition capability;

— data format.

4.5 Structure of the system

Seismometer systems can include the following components, as shown in Figure 1:

— seismometers for measuring environmental vibrations (e.g. seismic motion or volcanic ground motion);

— data obtained by seismometer;

— processing components;

— other peripheral equipment (e.g. communication infrastructure, power supply facilities, fixing devices).

When performing seismic observations at multiple points using the communication infrastructure, the following factors should be considered:

— the observation environments that are likely to impact the performance of seismometer systems;

— the spatial distribution of seismometer systems, including location, density and network.
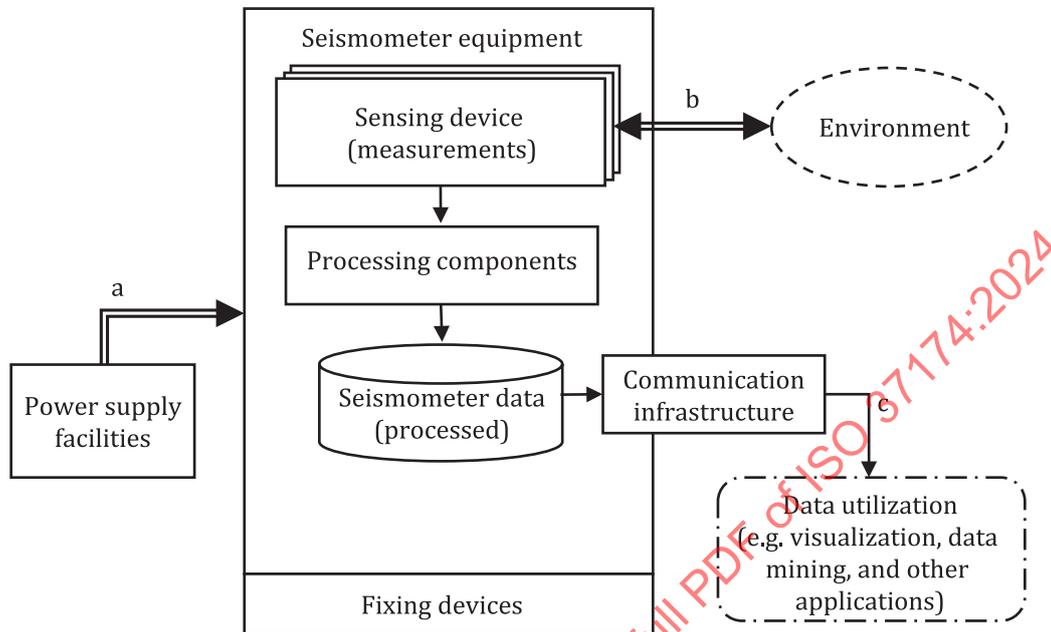
Key
a   Electric power.
b   Vibration caused by seismic motion or volcanic ground motion.
c   Data.

Figure 1 — Example of a seismometer system and interactions

Seismometer systems for communities can be implemented in various places for different purposes, as shown in Figure 2, in which number labels represent locations and letter labels represent purposes.
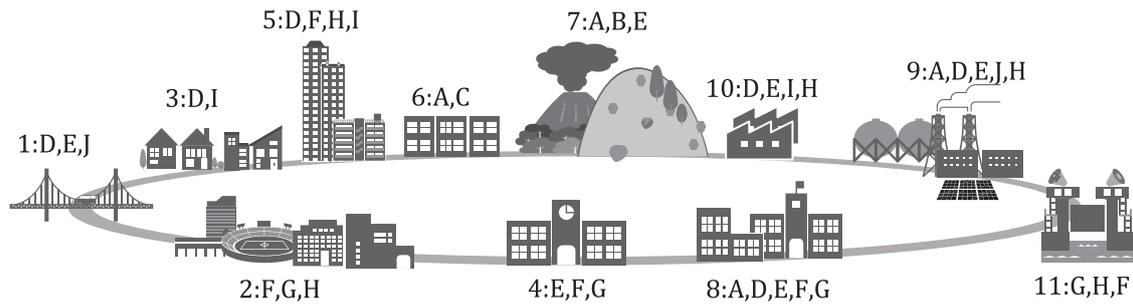
Key

Structures and areas

1   roads, bridges

2   shopping centres, amusement facilities, large meeting halls, hospitals

3   housing area

4   schools

5   high-rise buildings

6   laboratories

7   hazard areas

8   public offices

9   electric power, city gas facilities

10   factories

11   coastline

Purpose of seismometer systems

A   hazard area survey

B   volcanic tremor survey

C   micro-seismic motion monitoring

D   national disaster management network

E   local disaster management network

F   wide-area earthquake warning system

G   earthquake evacuation warning system

H   emergency stoppage system in the event of an earthquake

I   structural damage survey

J   structural deterioration survey

Figure 2 — Examples of the potential use of seismometer systems in a community

5   Utilization of seismometer data

5.1   General

5.1.1   Data acquisition

Planners, developers and operators of communities can utilize seismometer systems differently in various phases, including before, during and after disasters.

Planners, developers and operators of communities should therefore install the appropriate type of seismometer system, after considering how to use them in each phase.

Secondary metrics, such as magnitude and seismic intensity, can be calculated with seismometer data. For example, magnitude can indicate the amount of energy released by an earthquake. In addition, seismic intensity can indicate the site-specific strength of an earthquake and the potential damage.

5.1.2 Data specifications

5.1.2.1 Data to be acquired

Acceleration, velocity or displacement of motion should be acquired as time-series data. When conducting a spatial analysis, information on the location should be acquired, and time synchronization should be applied.

5.1.2.2 Data specifications

Acceleration, velocity or displacement of motion should be acquired with appropriate accuracy of time and location for the specific purpose.

5.1.2.3 Data format

A common data format can be used to enhance interoperability among the different seismometer systems.

5.1.3 Devices and facilities available for data acquisition

5.1.3.1 Seismometer

Guidance for a suitable amplitude least count, frequency range and sampling rate are provided in Annex B.

5.1.3.2 Arrangement of seismometers

The arrangement of seismometers should reflect the intended purpose. For example, to assess the vulnerability of an area, seismometers should be spatially distributed to cover the area. To assess the damage and soundness of a building structure, seismometers should be vertically distributed. More than one seismometer can be installed on multiple floors, if necessary.

5.1.3.3 Peripheral equipment

A power supply and a communication network should be provided. Additional power supplies for emergency purposes should also be provided. Seismometer systems should be installed following the manufacturer's specifications.

5.2 Utilization of data before disasters

Planners, developers and operators of communities can use seismometer systems, before a disaster occurs, for the following purposes:

— monitoring seismic and volcanic activity;

— investigating and understanding the hazard exposure of communities;

— identifying the spatial vibration characteristics of areas through a ground survey using microearthquake data;

— creating hazard maps and earthquake risk maps;

— diagnosing disaster resistance, soundness and deterioration of the instrumented structures (those with seismometers) in communities;

— building the capacities of communities and citizens as well as mitigating damage by using early warning systems for drills and emergency stoppage systems.

5.3 Utilization of data during disasters

Planners, developers and operators of communities can use seismometer systems, during disasters, for the following purposes:

a) immediately upon sensing the P-wave of an earthquake:

— for reducing the number of victims by using early warning systems;

— for preventing damage by controlling emergency stoppage equipment and systems;

b) immediately after detecting the ground motion caused by a strong earthquake:

— for estimating the characteristics of the earthquake, generating quick estimation maps of the earthquake disaster damage and making tsunami predictions;

— for promoting early evacuation to avoid secondary disasters due to tsunami;

— for rapid and remote estimation of the damage to instrumented structures;

— for preventing secondary damage caused by aftershocks;

— for preventing unnecessary evacuations from slightly damaged instrumented structures.

5.4 Utilization of data after disasters

Planners, developers and operators of communities can use seismometer systems, after disasters, for the following purposes:

a) emergency response:

— conducting emergency services, such as search and rescue, based on a rapid impact estimation;

— assessing the safety of instrumented structures by rapidly estimating the severity of structural damage;

— providing warning of aftershocks by monitoring seismic activity;

— carrying out emergency stoppage of gas, electricity and water supply facilities in the damaged area that can lead to secondary events;

NOTE   Secondary events include, e.g. aftershocks, tsunami, fires, power outages, caused by earthquakes.

b) recovery and reconstruction:

— assessing the damage to instrumented structures;

— prioritizing activities in reconstruction planning;

— analysing the recorded data to better understand the ground response and structural behaviour to improve the seismic design and seismic evaluation regulations as well as rehabilitation and methodologies for seismic risk assessment, and to make informed decisions on rebuilding, repairing and dismantling structures to assist in drafting a reconstruction plan that considers earthquake vulnerabilities.

6   Functions of seismometers and data use

6.1   Purposes of using seismometer systems

Seismometers should be selected to meet the user's purpose and intended contributions to disaster risk reduction (see Table 1 and Table 2).

Table 1 — Categorization of purposes for using seismometer systems

Classification	Purpose of use/ Category (see Figure 2)	Timing	Contributions to disaster risk reduction
Detailed survey data	Hazardous area survey/ Category A	When no earthquake is occurring (normal times)	Improving, constructing and developing seismic hazard maps as input for the assessment of disaster risk in urban planning
	Volcanic tremor survey/ Category B		Evaluating potential for volcanic eruption
	Micro-seismic motion monitoring/Category C		Identifying earthquake source and ground response parameters
Strong motion monitoring data	National disaster management/ Category D	When an earthquake occurs	Creating a quick estimation map for earthquake disaster damage Understanding earthquake disasters
	Local disaster management/ Category E		Evacuation plan according to the disaster situation Understanding earthquake disasters
Earthquake detection data	Wide-area earthquake warning/ Category F	When an earthquake occurs When a secondary disaster is imminent	Reducing loss of life Notifications of wide-area earthquakes
	Earthquake evacuation warning/Category G		Reducing loss of life
	Emergency stoppage in the event of an earthquake/Category H		Reducing equipment damage
Structure health monitoring data	Structural damage survey/Category I	When a secondary disaster is imminent	Reducing physical damage to structures (e.g. roads, bridges)
	Structural deterioration survey/Category J	When no earthquake is occurring (normal times) When a secondary disaster is imminent	Advance response plan Reducing physical damage to structures, roads, bridges, etc.
	Other purposes/ Category Z		

Table 2 — Subcategory table for additional functions

Classification	Function	Subcategory
Long-period motion data	Measurement of vibrations containing long-period components	+L

The use of seismometer systems described for each category is as follows:

a) Hazardous area survey (Category A)

Seismometer systems in this category investigate geological properties and identify vulnerable areas from the vibration measurement data from seismometers installed in multiple locations on the surface or underground. The geological information obtained from micro-seismicity data can be used to create a hazard map.

NOTE 1   For more information on geotechnical monitoring by field instrumentation, see ISO 18674-1.

b) Volcanic tremor survey (Category B)

Seismometer systems in this category monitor signs of volcanic eruptions and activity from micro-vibration measurement data from seismometers installed around a volcano. They also monitor the tremors

from volcanoes that have a possibility of eruption. When the area is judged to be dangerous, evacuation notifications are sent to surrounding communities.

c) Micro-seismic motion monitoring (Category C)

Seismometer systems in this category monitor the detailed properties of earthquake occurrences, their magnitude and focus. Detailed properties of the earthquake can be monitored from the micro vibration wave data from the seismometer installed at reference observation points. By using data from multiple locations, it is possible to acquire information for decision-making on the post-earthquake measures which could reduce the risk of damage from aftershocks.

NOTE 2   For more information on measuring vibrations and evaluating their effects on structures, see ISO 4866.

NOTE 3   For more information on array measurement of microtremors to estimate shear wave velocity profile, see ISO 24057.

d) National disaster management (Category D)

Seismometer systems in this category aggregate vibration data from multiple seismometers installed in the seismically active area using a countrywide network, and wide-area information on earthquake occurrences is monitored. The acquired wide-area information can be used for checking damage and planning disaster relief activities. This can include information on seismic intensity.

NOTE 4   For more information on instrumentation for national seismic systems, see Reference [20].

e) Local disaster management (Category E)

Seismometer systems in this category aggregate vibration data from multiple seismometers installed locally through a network, and information on earthquakes is monitored. The information can be used for confirming damage, planning disaster relief activities, as well as operating and managing roads and other parts of an infrastructure. Depending on the installation area, information on seismic intensity can be included. The seismometer network can be installed and managed not only by local governments but also by road operators.

f) Wide-area earthquake warning (Category F)

Seismometer systems in this category use vibration data from multiple seismometers installed in a wide area to issue a wide area warning for urging evacuation and warnings by broadcasting media and mobile communication networks. The strength of seismic waves and the seismic intensity set for each country are used as the criteria for issuing warnings. In addition, an alarm can be issued to the area before the arrival of the earthquake tremors by using the difference in arrival time of the seismic waves at multiple locations. A seismometer system in this category can be operated to issue evacuation warnings over a wide area. In some cases, observational and warning capabilities can be implemented as two separate systems.

NOTE 5   For more information on the implementation of a community-based disaster early warning system, see ISO 22328-1.

g) Earthquake evacuation warning (Category G)

Seismometer systems in this category use vibration data measured by one or more seismometers to send warnings to specific locations and facilities to urge evacuation and caution. These alerts can be used for evacuation drills to help reduce the loss of life. The strength of seismic waves and the seismic intensity set for each country are used as the criteria for issuing warnings. Seismometer systems in this category can be installed in, for example, schools, commercial buildings and theatres, and are used to evacuate people in the event of a disaster.

h) Emergency stoppage in the event of an earthquake (Category H)

Seismometer systems in this category use vibration data measured by one or more seismometers to activate the emergency stoppage of facilities in operation and to activate disaster prevention equipment. The strength of the seismic wave is used as the criterion for activation. When an event above the criteria

threshold is detected, the seismometer system immediately stops power generation or factory automation, sluices, etc.

i)   Structural damage survey (Category I)

Seismometer systems in this category investigate the post-earthquake condition of a structure using vibration data measured by one or several seismometers. The seismometer systems estimate the soundness of the structure using the amount of displacement and the structure's natural period. Through this survey, the deformation of, for example, high-rise buildings and towers, can be grasped, and assessments can be made on whether continuous use is possible after a disaster.

NOTE 6   For more information on performance parameters for condition monitoring of structures, see ISO 16587.

j)   Structural deterioration survey (Category J)

Seismometer systems in this category investigate the condition of a structure using vibration data measured by one or more seismometers. The soundness of the structure is estimated by using not only the earthquake tremors but also the vibrations generated by traffic. Through this survey, the deterioration of important infrastructure, for example, bridges and tunnels, is determined. The survey can also be used to predict whether these structures can be used after an earthquake.

NOTE 7   For more information on dynamic tests and investigations on bridges and viaducts, see ISO 14963.

NOTE 8   For more information on evaluating measurement results from dynamic tests and investigations of bridges, see ISO 18649.

k)   Other purposes (Category Z)

When seismometer systems are used for a purpose that does not fall into the categories from a) to j), category Z is applied.

l)   Long-period motion data (Subcategory +L)

If the seismometer data includes long-period ground motion component, "+L" is attached after the category notation. For example, a wide-area earthquake disaster prevention network containing long-period component data is described as category D+L, and an earthquake damage survey including long-period component data is described as category I+L. Earthquakes contain waves with various periodic components. Structures such as high-rise buildings, long bridges, and oil tanks can be damaged by long-period component waves.

NOTE 9   Mapping the use of seismometer systems to the disaster-management process and the ISO 37123 indicators are provided in Annex C.

6.2   Functions of seismometer systems

Seismometer systems consist of seismometers and servers. They can record seismic data and connect to external controllers.

Seismometer systems should be distributed within an appropriate geographical area and density for the observed data to be utilized effectively.

Seismometers should be firmly secured to structures in the infrastructure, such as the ground or the surface of buildings, equipment or facilities, to accurately measure seismic vibrations.

Seismometers should be robust against disasters. Waterproof or explosion-proof types should be selected depending on the location where they will be used.

7 Ensuring availability and interoperability of seismometer data

7.1 Ensuring availability of seismometer data

Planners, developers and operators of communities should assess the risk of seismometers and networks being damaged after a disaster and take actions to reduce the risk. This includes assessing ground conditions, choosing effective protection against water and dust based on the surrounding conditions, and ensuring traceability of the seismometers.

Planners, developers and operators of communities should recognize that, in addition to the performance test of the seismometer system after installation, the long-term management of the seismometer system (including calibration, maintenance and inspection) is also important to properly prepare for earthquakes. Seismometer systems should be managed, including choosing an appropriate maintenance period based on the vulnerability of the area, to ensure the continued effectiveness of the seismometer system.

NOTE 1   For more information on important characteristics to be specified for seismic pick-ups, see ISO 8042.

NOTE 2   For more information on methods for the calibration of vibration and shock transducers, see ISO 16063-1, ISO 16063-11, ISO 16063-21, ISO 16063-31 and ISO 16063-42.

NOTE 3   For more information on methods for mechanical mounting of accelerometers, see ISO 5348.

Planners, developers and operators of communities should consider preventive measures for theft and information security threats related to the seismometer system.

Planners, developers and operators of communities should also build the capacity of workers to install, maintain and operate the seismometer system.

7.2 Ensuring the interoperability of seismometer data

Planners, developers and operators of communities should consider cost effectiveness and use a standardized data format and data exchange method for seismometer data as much as practically possible to ensure interoperability among different actors.

Planners, developers and operators of communities should also describe the conditions of observations so that a third person is able to interpret the data correctly.

Ensuring interoperability has many benefits. If interoperability across multiple regions is achieved, it will become possible to utilize data in a wider area for better decision-making, such as issuing tsunami warnings using earthquake data acquired in other areas. If interoperability across multiple systems is achieved, it will become possible to broaden the utility of data, such as applying seismometers used for monitoring structural health in the context of emergency stops of elevators.

Annex A
(informative)

Example of seismometer data categorization selection

Figure A.1 is a flowchart for determining the appropriate seismometer system for a specific purpose.

```
┌─────────────────────────────────┐
│  Determine the purpose of        │
│  implementing a seismometer      │
│  system                          │
└─────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────┐
│  Select the usage that is close  │
│  to the purpose from the usage   │
│  example in Table 1              │
└─────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────┐
│  Determine the selected category │
│                                  │
│  Add L if long-period component  │
│  is required                     │
└─────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────┐
│  Refer to the data specifications│
│  corresponding to the category   │
│  from Annex B (Table B.1,        │
│  Table B.2 and Table B.3)        │
└─────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────┐
│  Determine a seismometer system  │
│  that meets the specifications   │
└─────────────────────────────────┘
```
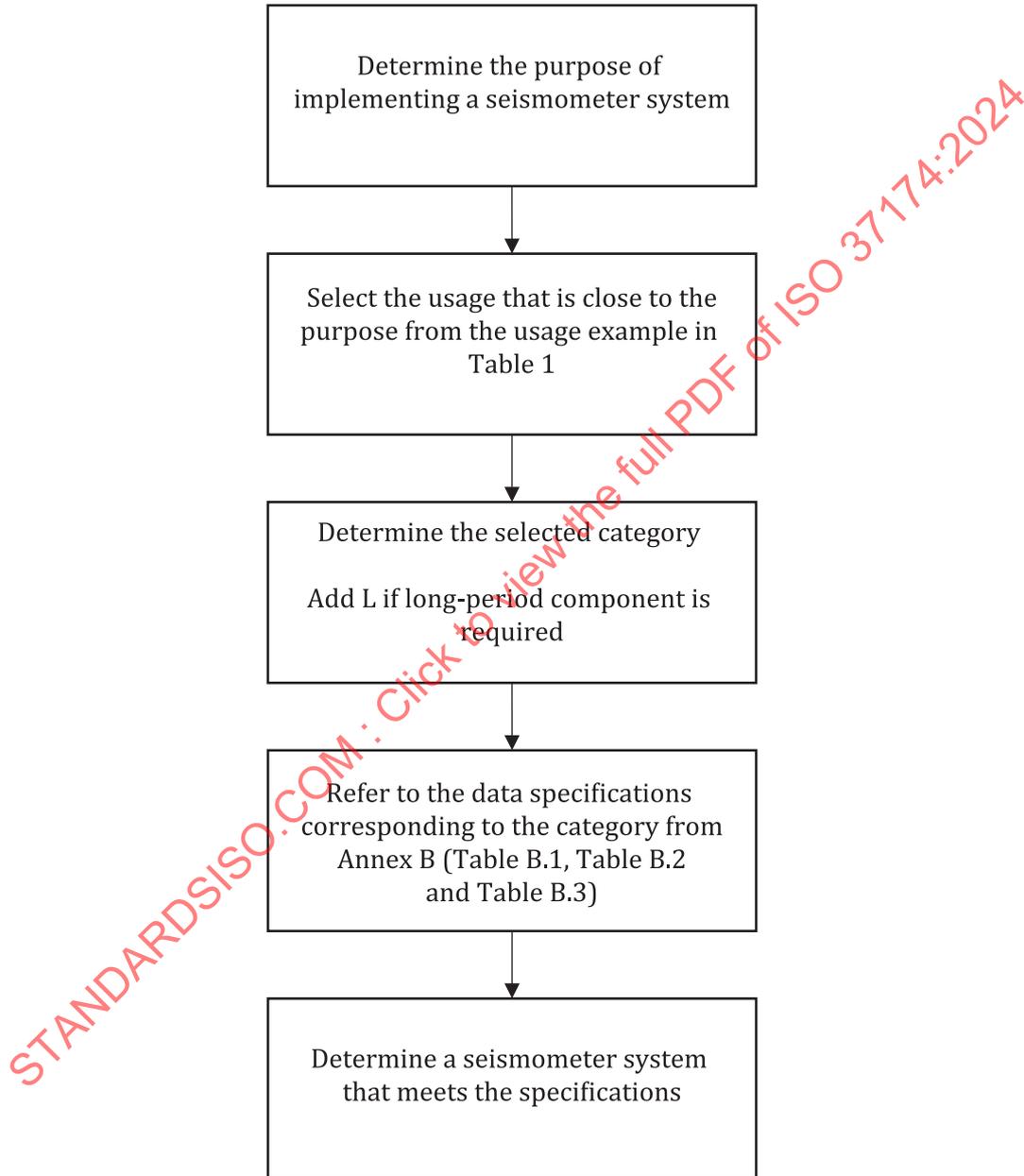
Figure A.1 — Flowchart for determining seismometer systems for specific purposes

Annex B
(informative)

Recommended data table by category

Table B.1 and Table B.2 show the performance of seismometers recommended for each category (see 6.1). When selecting seismometer systems, the characteristics appropriate for the specific purposes should be taken into account. Table B.3 provides characteristics that cover all categories of seismometer systems. For guidance on specifications of the data related to the characteristics of seismometer systems, see 4.4.

Table B.1 — Recommended performance of seismometers corresponding to each category

Category	Purpose of use	Physical quantity	Frequency range	Amplitude least count	Amplitude range
A	Hazardous area survey	Select from either "acceleration" or "velocity"	Range corresponding to ground information for each location	Resolution corresponding to ground information for each location	Range greater than expected maximum change
B	Volcanic tremor survey	Select from either "acceleration", "velocity" or "displacement"	Range for monitoring volcanic tremors	Resolution for volcanic tremor monitoring	Range for monitoring volcanic tremors
C	Micro-seismic motion monitoring			Resolution that can identify micro-seismic motion	Expand the range shown in ISO 4866 according to the installed object
D	National disaster management	Select from either "acceleration" or "velocity"	Expand the range shown in ISO 4866 according to the installed location	Resolution that can record felt earthquakes	
E	Local disaster management				
F	Wide area earthquake warning				
G	Earthquake evacuation warning		Range that can cover the influence of the installed object	Resolution required for issuing alerts	Range for effective evacuations
H	Emergency stoppage in the event of an earthquake				Below the maximum amount of change in the installed object
I	Structural damage survey	Select from either "acceleration", "velocity" or "displacement"	Range corresponding to the response of the installed structure	Resolution that can record felt earthquakes	
J	Structural deterioration survey			Resolution that can discriminate micro-vibration	Equivalent to the range shown in ISO 4866
Z	Other purposes	Arbitrarily specified	Arbitrarily specified	Arbitrarily specified	Arbitrarily specified

Table B.2 — Subcategory for additional functions

Subcategory	Function	Physical quantity	Frequency range	Amplitude least count	Amplitude range
+L	Long-period seismic motion measurement		Range including 0,05 Hz and above		
NOTE 1 Long-period seismic motion sometimes causes damage to structures, such as oil tanks, high-rise buildings, bridges and transmission towers.					
NOTE 2 Subcategories are used, such as category D+L, to add functionality to categories.					