Sensonics Technical Note – DS1224

Seismic Protection and Monitoring Systems for Nuclear Installations

1. Introduction

The systems are designed to provide the following primary functions:-

i) A secure and extremely dependable alarm to the plant operational staff when a seismic event of greater magnitude than a predetermined level occurs, thus allowing the rapid shutdown of plant processes in a controlled manner.

ii) To record the seismic event and allow playback of time waveform, level and spectral data to establish the likely effect of the event on the plant structure.

A Seismic detection system normally comprises of a minimum of three triaxial seismic switches mounted at least 10m apart on the superstructure of the building to be monitored. The seismic detectors are wired to a central equipment cubicle located close to the control room.

The seismic detectors provide a seismic event alarm at the operating base earthquake (OBE) level that should be set above the anticipated background vibration level. However, to protect against spurious trips, the following precautions are taken.

- Three sensors operating in a two out of three logic are employed
- The sensors are spaced at least 10m apart from each other
- The sensors are placed in positions where personnel access is not normally required, and is restricted.

2. General Functions

The following are the principle functions of the system.

2.1 Primary Functions of the System

The primary functions of the systems are:

a). To provide plant operational Staff with immediate warning of a Seismic event which exceeds a predetermined intensity (amplitude) to enable them to bring the reactor to a safe condition in a controlled manner.

b). To record the time history of any such Seismic event and allow post-event playback of frequency and amplitude data to determine the likely cause of the alarm and to estimate the extent of damage to the reactor and its surroundings.

2.2 Other Features of the System

Whilst providing as effective monitoring as possible it is also necessary to reduce spurious alarms to an acceptable level.

The most likely cause of spurious alarms is local activity e.g. movement of vehicles, maintenance activities etc. Therefore to eliminate these non structure-threatening incidents three widely dispersed seismic switches are employed and a 2 out of 3 voting system utilised. The seismic detectors are set to trip at the Operating Basis Earthquake (OBE). The OBE level is chosen to give an adequate margin over and above the background ground vibration level.

In order to ensure correct operation of the system, a facility is provided to allow frequent functional checks to be made with the minimum loss of seismic event monitoring.

The seismic detectors are rigidly mounted to the main foundations of the reactor building where the structure is directly connected to the bedrock below.

The equipment supplied is based on a seismically qualified standard monitoring system.

The replay software runs on a portable PC which can be stored away from the system in a protective case and so does not require Seismic qualification. The portable PC can be connected to the data recording system when required via an RS232 link.

Failure Mode and Effect Analysis, Reliability Analysis and Availability Analysis are produced to ensure the system meets with the operational demands.

The supplier recommends a proactive maintenance regime for the correct operation of the system.

2.3 System Installation Requirements

2.3.1 Physical

The seismic equipment cubicle typically measures 800mm wide, 950mm deep, and 1925mm high (excluding the removable eyebolts). The cubicle stands on a plinth that may be up to 250mm high. Access is required to the front and the rear of the cubicle. The cubicle should be securely bolted to the floor, and located in a position where it will be adequately protected against secondary seismic hazards.

2.3.2 Electrical

The seismic equipment cubicle requires a 110V ac, 50 Hz, supply rated at 10A or greater. The incoming/outgoing cables may enter via either the top or the bottom of the cubicle.

3. General System Description

3.1 General

Ground motion is detected by means of three 'Seismic Switches' distributed around the site. Each switch comprises three orthogonally mounted seismic pick-ups together with electronic circuits which amplify and filter the signals produced by the pick-ups and compare these with a pre-set, adjustable threshold. If any signal exceeds this threshold, then a relay changes state. The relay contacts remain in the changed state for a (factory) pre-set length of time (0<10 sec) after the ground motion signal falls below the pre-set threshold. When this time period has elapsed, the relay and its contacts return to the original state ready for the next event.

If two seismic switches have tripped the voting system considers that a genuine seismic event has occurred and initiates the seismic event alarm output. The seismic event alarm is indicated in the Central Control Room.

The analogue dynamic signal from each of the 9 (total) seismometers is transmitted via a BS5308 armoured, individually screened, twisted pair cable to the central monitoring cubicle. The cables are sheathed in LFH material.

Each equipment assembly within the overall system contains detection circuits for 'equipment failure', and provides relay contact outputs for indication within the central monitoring unit. All the equipment fault alarm relay outputs from all the individual units are connected in series. A failure in any one of the units will cause a relay to open that will bring up a group system fault alarm on the master annunciator rack and provide a relay output for remote indication of the fault on the Group Warning system.

The system operates from a 24V dc power supply rack that is powered by a 110V, 50 Hz floating ac supply. In the event of mains failure the system will continue to operate for up to 3 hours on rechargeable batteries located in the equipment cubicle.

3.2 Test/Calibration Facilities

Routine calibration checks of the seismic monitoring system are achieved by means of a reference signal generated in the seismic equipment cubicle and connected via switches to the input of each seismic switch unit in turn.

It is a requirement that during calibration checking the system should not be taken off-line. The seismic switches can therefore be calibrated individually, while the system continues to function from the other two switches. During this period the seismic event alarm will be initiated if either of the other two switches trips (i.e. the voting system will continue to operate on 1 out of 2 logic).

The 2 out of 3 alarm voting system is duplicated and a facility to switch from one voting system to the other provided. In this way each individual voting system can be functionally tested whilst the other remains on-line.

Following calibration a system test should be performed. This is the only time that the system will be 'off-line' and should be limited to no more than 2 minutes.

3.3 SA-3 Seismic Switch Seismometers

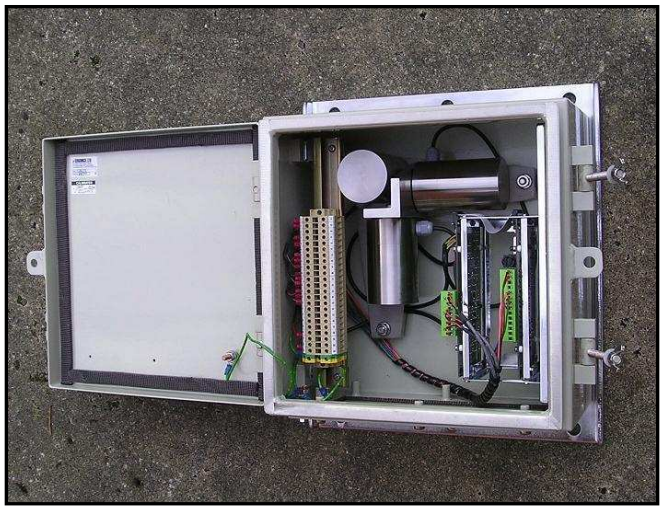
Each of the three 3-axis seismic switches are mounted on a vertical surface that is an integral part of the building structure. Each unit is to be held rigidly to the building structure by means of three anchor studs set into the concrete walls.

The housing for each seismic switch is identical and comprises a painted steel enclosure attached to a plated steel mounting plate provided with three mounting holes. The housing has a hinged lid held closed by a pair of wing nuts. The wing nuts, when tightened, pull the lid and housing together into a captive gasket which maintains the sealing of the enclosure to IP66 rating. The lid is to be padlocked to prevent unauthorised access during normal operation. A 10 pair, LFH cable enters the housing via the lower gland plate and is terminated at Klippon terminals mounted within the enclosure.

Power for operation of the seismic switches is supplied, via the 10 screened twisted pair cable, from the 48V dc power supply unit located in the seismic monitoring equipment cubicle.

The seismometers are based on Sensonics SP4 accelerometer technology. In the seismometer the signal output from each accelerometer is processed through an integral 3 channel seismic amplifier board where electronic filters damp out any higher frequency noise signals. Normally the filter –3dB point is set to 30 Hz. The full sensor specification is as follows.

Sensing Element	Piezoelectric.
Sensitivity	4V/g normalised to within +/-1%.
Frequency Response	0.1Hz up to 1KHz (3dB).
Measurement Range	120dB dynamic.
Noise Floor	2ug rms typical @ 25°C.
Linearity	0.1% full scale.
Shock limits	1000g peak any direction.
Excitation	±12V DC
Operating Temperature	-30°C to +70°C.



SA-3 Siesmic Seismometer & Switch

From the amplifier board the signal is routed to the current output board where circuits convert the signal voltage to a signal current suitable for driving distances in excess of 500m in the plant cabling between the seismometer and equipment cubicle.

To ensure current loop integrity can be monitored the quiescent loop value is set to 12mA.

All accelerometers have compensation and normalising circuits so the output of each will be identical for a given input acceleration.

The fault alarm function is a normally energised relay and associated circuitry which continuously monitors the dc voltage from each accelerometer and the power rails; this will be de-energised if any value falls outside the set limits.

The calibration function is driven by signals from the calibration rack, these direct a 1 hertz sine wave signal to an additional piezo crystal within the accelerometer, this excites the mass to cause a known output for that axis on the measuring crystal stack.

The input signal can be injected at either of 2 levels for each axis under the control of the selector switches on the calibration rack. These levels correspond with those for the OSE and SSE trip values in the voting circuit.

Using the cal check function with the SP4 confirms satisfactory function of the entire signal path for each axis; this obviates the need for the removal of the seismic sensors for re-calibration that is necessary on other manufacturers systems.

Note: - the calibration levels will be the same for each seismometer.

3.4 Seismic Data Recorders

The seismic system data logger is an industrial ruggedised P.C. with the following features:-

a). Processor card using a 3.0G Pentium processor.
b). Analogue to digital input card with additional digital input/output functions.
c). Watchdog card.
d). PCMCIA silicon disk card.
e). 2 x SD drive for ‘event’ storage and data transfer.
f). Drawer mounted keyboard with 17” LCD monitor.

Externally mounted on a terminal rail is a digital output to relay conversion board.

3.4.1 Operation of Data Recorders

The three axis current loops from each of the three connected seismometers are terminated at the interface rack via the plant cabling terminal rail, within each channel input position is fitted a precision resistor connected to complete the loop from the seismometer.

A voltage, nominally 3V dc, will be generated across each precision resistor; these are wired to the A to D input/output card in the industrial P.C. as well as being fed to the interface rack comparator circuits

Each signal voltage is sampled and recorded in digital form at a rate of 256 samples per second.

On initial booting up into the Seismic recording program the processor will monitor the voltage level for each of the 9 accelerometer axes in order to establish the average value for each axis. This takes approximately 2 minutes.

The average value for each axis is then used as a base line to establish the zero acceleration level and also to confirm channel integrity. The long term average value is continuously updated so that in the event of any drift in a channel loop value there will be no resultant deviation from a zero ‘g’ average.

Acceleration levels for all 3 axes for each seismometer are continuously monitored by the PC and compared with a value selected during system commissioning.

The digitised signal voltage is stored in the PC’s silicon disk memory card in a circular buffer to capture pre-event waveforms. Where no accelerations are experienced above a selected level the stored data will eventually be overwritten by new data in the buffer.

If a seismic acceleration is detected above the selected level then an event recording is triggered.

Data for all 9 axes for the period when accelerations are greater than the preset is stored in the event log. In addition the data for the following time period, duration set-up during commissioning, is also recorded, as is the data for the preceding time period, again the duration of which is set up during commissioning.

The logged event will therefore contain acceleration against time history for all axes made up from pre-event, event, and post event time periods.

On completion of the post event time period the record will be transferred to the A SD drive. Should this be defective, full or not inserted, the data will be written to the B SD drive.

The event is also stored on the silicon disk until manually erased.

The base seismic data recording program is based on the 6.2 DOS system for reliability. A Microsoft Windows compiled variant is also available.

Within the P.C. a watchdog card monitors the processor operations and maintains a health alarm relay in an energised condition, provided regular refresh signals are received, the refresh signal is created by the seismic recorder software program, if the program stops for whatever reason the watchdog card will create a fault alarm to the annunciator rack and onwards to the station alarm system inputs.

A drawer mounted keyboard and LCD display monitor for each recorder is included in the system. These are used when completing routine maintenance and functional checks to monitor the recorder system status and operations and to control the functions under test. They could also be used for reviewing any recorded event data.

Functional checks of the recorder system can be completed by signal injection similar to the seismic alarm testing, with the exception that in this case the triggering of a recording will happen whenever any of the signals exceed the pre set value for the recorder PC. If both the low and high calibration levels are above the recorder pre set then all selections on the Calibration rack will initiate recordings.

Playback analysis of the records can then be used to confirm the function of the calibration system.

Pre set values for the recording system are usually chosen to be below those for the seismic alarms so that any smaller scale seismic activity can be recorded.

3.5 Replay and Analysis Software

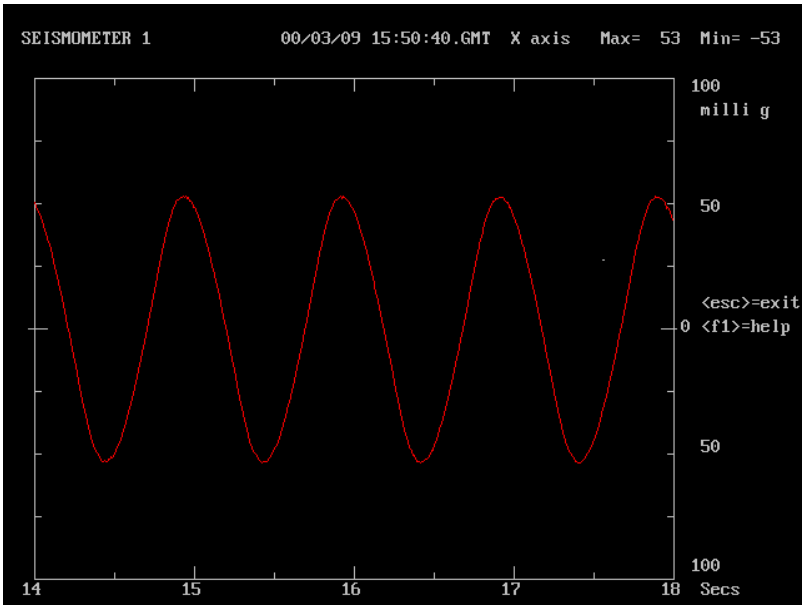
Software is provided for a remote PC for the replay and analysis of any seismic data.

The events can also be viewed through the main system recording facility.

Seismic data is transferred by removing the SD card from the A drive of the recorder system processors, or the B drive if a fault condition for the A drive is indicated for the recorder.

Replacement SD cards must be inserted into the empty drives immediately on removal of the disk containing seismic data (otherwise an alarm will be generated).

After copying the recorded data into the replay processor the acceleration against time recorded history of each discrete event can be viewed as a trace upon a graph, the normal view is of 4 second sections of the record, however the trace can be compressed in order to view more of the event on screen.

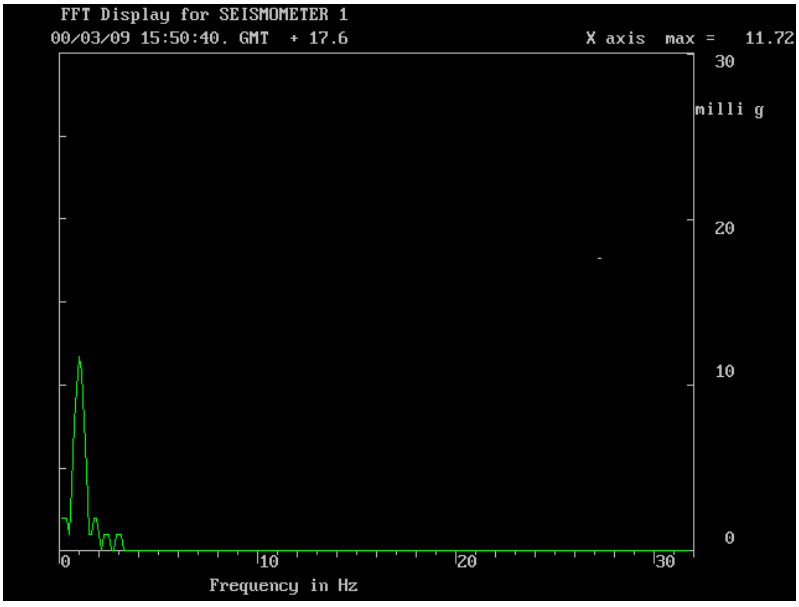


Typical time waveform display

Keyboard function keys are utilised for access to the menu parameters.

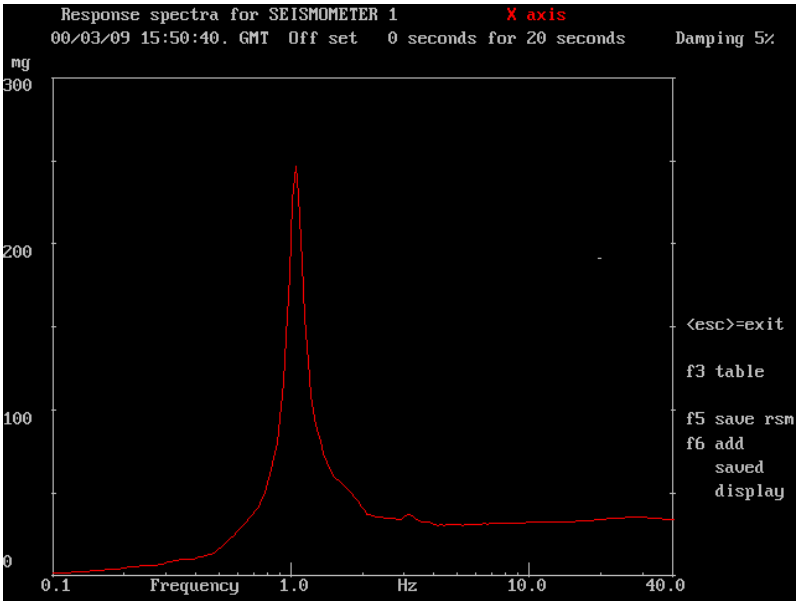
It is possible to view all 3-axis waveforms simultaneously. A zoom facility is provided for the magnitude axis to enable appropriate scaling. A capture facility permits the waveforms to be saved in an image format for exporting to report documents.

The event frequency analysis takes two forms, the first is to convert the acceleration trace by completing an FFT analysis to the frequency domain, this provides an indication of the amplitude and frequencies of the event recorded.



Typical FFT display

The second analysis is to obtain a response spectrum graph of maximum acceleration values that would be experienced by any structures with resonant frequencies of up to 40 hertz.



Typical Spectral Response display

The response spectrum uses 200 models of single axis freedom with a damping factor of 5% for frequencies between 0.1 Hz to 40 Hz.

3.6 Alarm Interface Rack

The current loop signals from each axis of each seismometer are wired to the input terminals of the interface rack.

A high precision resister is fitted for each channel within the rack; this generates a voltage, nominally 3.0 volts dc, for a quiescent state acceleration signal. The voltage produced is wired to the appropriate input pin to the recorder A to D input card, to provide the seismic input data.

Within the interface rack each channel signal is fed via a full wave rectifier to two comparator circuits, these compare the incoming signal with a pre set value representing the SSE and the OSE acceleration figures for that channel.

Should the incoming signal exceed the preset value a trip condition will be created and a relay for that channel will change state to provide an input signal for the voting logic rack.

Front panel mounted LED’s illuminate to indicate the tripped status for each channel at each level.

By using the calibration rack controls and internal signal source an output signal from each seismometer can be generated at levels just above either the OSE or SSE values, this allows testing of the trip circuits, and when used in combination, the voting circuits and alarms.

3.7 Voting Logic Rack

The function of the voting logic circuit is to monitor the trip conditions state from the interface rack for each axis in each of the seismometers, in the event that 2 or more voted trips occur at the relevant level and axis the voting rack will cause relays to change state and so doing cause the alarm to the control room to be raised.

Principles of Operation of the Voting Alarm Systems

a). Alarm Voting

Under normal operating conditions (i.e. calibration check not selected), when two seismic switches trip nearly-simultaneously (i.e. within the delay period of 0 to 16 seconds pre-set within the seismic switches) the voting system will deem that a seismic event has occurred. A 'Seismic Event' Alarm will be initiated together with the appropriate 'Seismic Switch Activated' alarm(s). The Event Alarm will remain activated until manually reset by the operator.

b). Seismic System Fault Alarm

This group alarm will be initiated by any of the alarms indicated on the slave annunciator rack. These alarms will in turn be initiated by a group of faults indicated by diagnostic LED's located on the originating racks. This will provide a diagnostic chain of failure indicators from overall system fault down to specific failures.

Each main circuit board within the local alarm voting and diagnostic system has a PSU integrity alarm indicator (a green PSU OK LED) which is visible via the rear door. If such a failure occurs within the alarm voting and diagnostic system, an additional fault relay initiates a Seismic System Fault alarm.

The rack contains two circuits one for each of the OSE and SSE voted alarms.

3.8 Calibration Test Rack

The function of this rack is to provide the facilities to test the seismometer signal path, recorder trip levels and axis trip and voting logic.

A calibration signal can be directed to each sensor axis, the signal from the rack is normally set to 1 hertz and at a fixed level, the actual voltage for the 2 levels required for each axis is set within the seismometer by attenuation circuits for each axis.

In addition to the internally generated 1 Hertz signal a facility is incorporated to allow an external calibration signal to be routed through the rack, this signal may be at higher frequencies, up to the filter cut off at 30 Hertz.

The seismic monitoring system is designed so that each of the three seismic switches and both of the two out of three alarm voting systems can be individually checked for correct functionality while the system remains operational.

There is also the facility to check the system function as a whole, from signal injection at the seismic detectors to the indication of a seismic event alarm. The system will be off-line for the duration of the test. The two out of three voting

system can be checked in 2 minutes using a single combination of two tripped sensors, but a full check involving all combinations of tripped sensors may take up to 10 minutes.

The Calibration Rack RA.8124 is located in the seismic monitoring equipment cubicle, provides facilities for generating and switching the calibration signals required for functionally checking the triaxial seismic switches.

The front panel contains one key operated switch and three rotary selector switches. The key operated switch enables an authorised person only (keyholder) to operate the calibration unit. The key can only be removed when the system is in the 'normal' position. This eliminates the possibility of a seismic alarm signal being generated accidentally by an unauthorised person.

In the 'normal' position the seismic monitoring system remains in normal operation and the calibration signal will not interfere with the seismic detectors.

The rotary switches select the calibration signals to the detectors. Each switch has seven positions: off, X Lo, X Hi, Y Lo, Y Hi, Z Lo, and Z Hi, and is allocated to an individual seismic triaxial detector.

With this rotary switch arrangement the user is able to select one or more seismic detectors for activation at the same time. The alarm voting systems can be checked when two or more seismic detectors are activated.

The X, Y, Z and Hi, Lo selection is achieved by BCD-coded digital signals transmitted to the three seismic switches via the 10 screened twisted pair cables.

The front panel keyswitch also operates a relay providing a signal to the master annunciator rack, indicating that the seismic switches are not in normal operation. The 'seismic calibration check' indicator on the master rack front panel will illuminate.

These checks should be carried out at the following intervals (to be confirmed by the availability/reliability analysis).

Trip levels	- Weekly
2 out of 3 Voting	- Monthly
System Check	- Monthly

3.9 Battery Backed Power Supply Racks

During normal operations the seismic triggering system is powered by dual dc supply racks each of which has sufficient capacity to power the circuits, and also a battery charging circuit to provide a charge to a battery pack at 24.0 volts.

The dc power is derived from the 110V 60 Hz ac input through transformer and regulated control circuits. Indicating LED's are provided to show satisfactory supply status for both the normal power supply and the battery charger supply and that the battery pack (if required) is connected.

A health alarm relay is provided in each power supply and a further relay connected to the battery pack which will provide alarm contacts to the alarm system if power failure occurs in either circuit or the battery pack is disconnected.

When mains power is lost the battery packs (if fitted) will maintain supplies to the Seismic Alarm System, this comprising all of the cubicle racks except the recorders which have their own UPS racks, plus all of the seismometers, until the battery packs become discharged.

The target battery back up time period is 3 hours, Yuasa extended life batteries can be used with a capacity of 70 A hours to ensure the back up time is maintained to beyond the recommended replacement lifetime of 5 years.

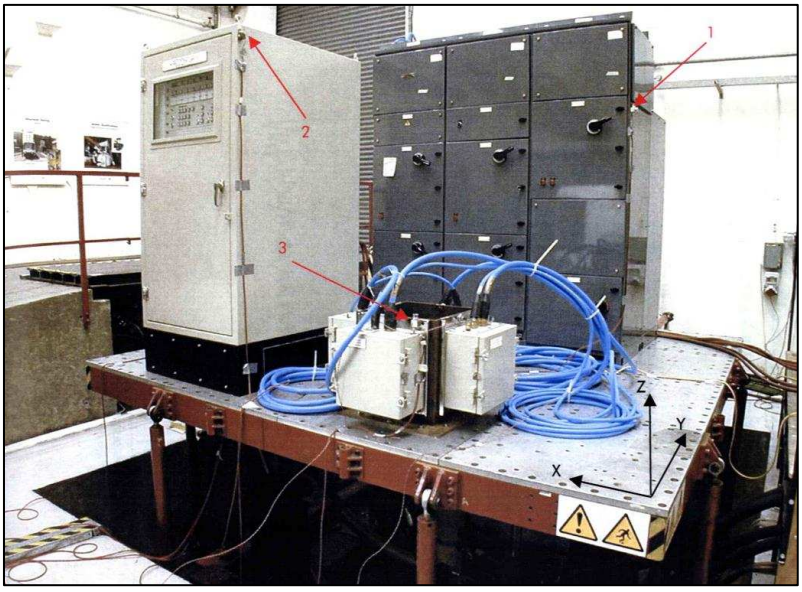
3.10 System Cubicle

The seismic system cubicle will be provided with the following facilities.

- Seismically Qualified Cubicle to IEEE std 344
- Dimensions 1775mm x 800mm x 950mm deep (inc plinth)
- Fully wired for application
- Alarm Shutdown interlocks and mains power isolators
- Distribution terminal rails (20% spare) and resettable fuse arrangement
- De-humidifiers
- Convenience sockets and internal lighting
- Earth bus bars for cable screen terminations
- EMC to Def Stan 59-41

All power supply racks will be housed in the panel, the alarm indications, interface and voting racks, and the recorder P.C. will also be housed in the panel such that all indicators will be visible through the door panel glass.

The picture below illustrates a full Sensonics seismic protection system undergoing type testing on a earthquake simulation table.



1. Customer Isolator Panel

2. System Cubicle

3. Seismic Switch / Seismometer Arrangement

Mains power for the system will be fed via changeover relay contacts, if this power feed is lost, the relay will operate and bring in an alternative power supply if available to the system.

An alarm will be raised and local indication will be provided to indicate normal power supplies have been lost.

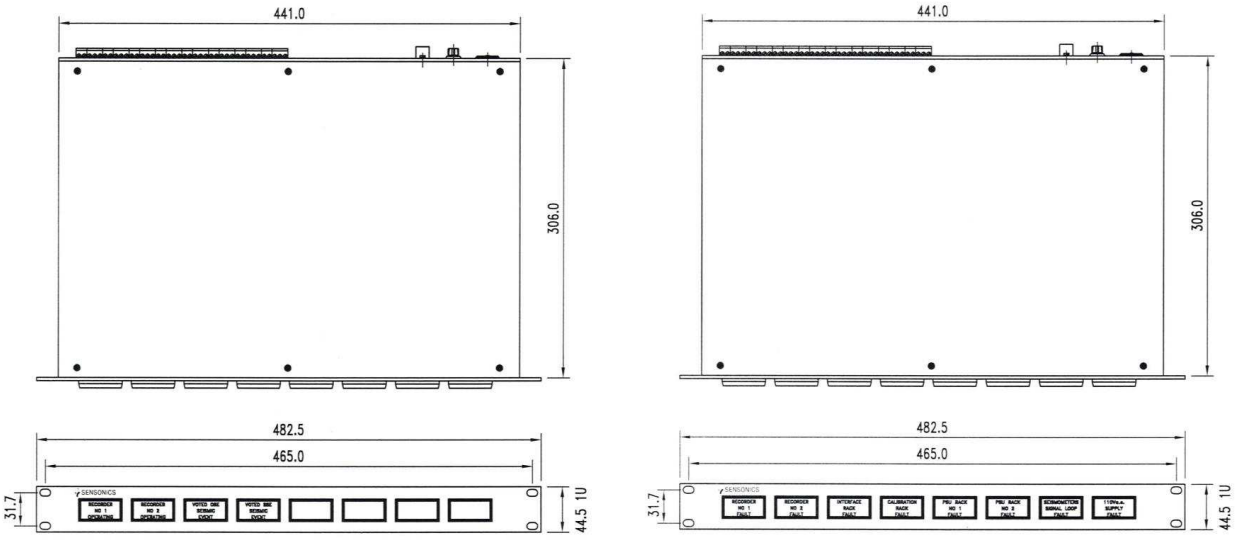
The alarm outputs from the seismic system are set as latching as standard and will have to be reset at the system cubicle.
The alarms for this system do not have a flashing mode so there is no accept function.

3.9 Interfaces

The Seismic Monitoring and Triggering System is for the most part a stand alone system. Other than the power supplies to the system the only customer interface connections are alarm outputs to the main control room for the shutdown function.

The interfaces between the seismic switches and the main system panel shall be made with individually screened twisted pair cable in a multi-core armoured arrangement.
Recommended - BS5308 PT1 Type 2 16/0.2 overall diameter 20.9mm.

Two separate indicator racks are fitted to the panel to provide high visibility indication of the alarm status. One rack is for fault indication, the other for event indication (see below).



4. Equipment List

The following list covers all the items supplied by Sensonics.

Table 1 Equipment List

Item	Description	Quantity
1	Seismic Switch	3 off
2	Seismic Monitoring Cubicle	1 off
3	Master Alarm Annunciator Rack	2 off
4	Slave Alarm Annunciator Rack	1 off
5	Interface Rack	1 off
5	Calibration Rack	1 off
6	Seismic Recorder	1 off
7	110/24V PSU Rack with Back-up	2 off
8	24V Battery Pack	1 off
9	Replay Software	1 off

5. Environmental Performance/Withstand

Temperature - 40^{o}C for 24 hours
Humidity - 90% non condensing
EMC - EN61326, Def Stan 59-41
Earthquakes - The equipment has been seismically qualified to IEEE Std 344 (see ALSTOM report ETC(M) C.91.205).

6. Design Life

The design life of the equipment is 20 years.

Please contact Sensonics to discuss your application further.

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