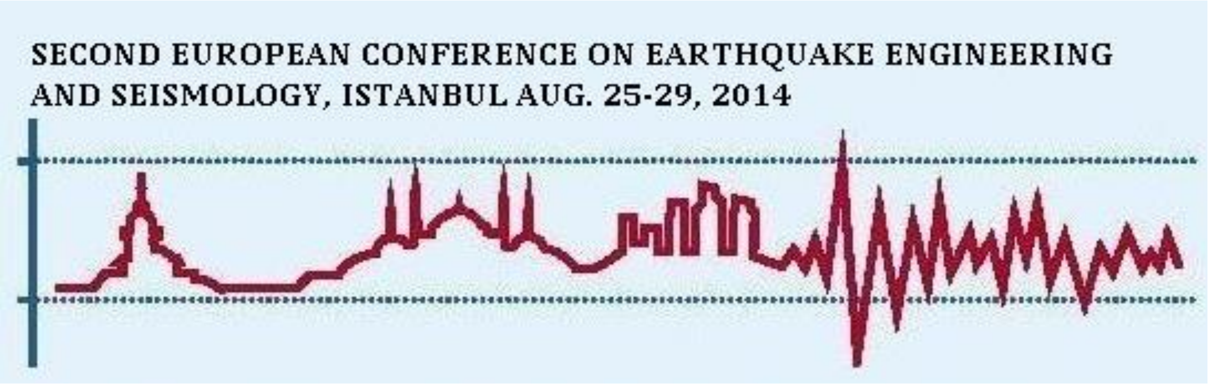
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# STRONG-MOTION MONITORING AND ACCELEROMETRIC RECORDINGS IN ICELAND

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## ABSTRACT

The purpose of this study is to describe strong-motion monitoring and accelerometric recordings in Iceland and to highlight some basic characteristics of the tectonic regime that governs earthquakes within Iceland and the surrounding region; furthermore, to outline the available data and provide information on their processing.

Strong-motion monitoring and recording have been carried out in Iceland since the early seventies. The Icelandic Strong-Motion Network, established in the mid-eighties, provides countrywide coverage of the most important seismic zones. The objective of the network is to collect strong-motion data required for structural design and risk management.

Ground-motion data during earthquakes having magnitude greater than 4 are accessible through the Internet Site for European Strong-Motion Data, http://www.ISESD.hi.is. The internet database contains raw data, i.e. uncorrected time series; corrected acceleration series; derived velocity series; linear elastic response spectra; and associated seismological parameters, including earthquake magnitude, source distances, site characterisation, peak ground acceleration (PGA) and velocity.

## INTRODUCTION

Iceland is an active earthquake area. Over the centuries, earthquakes have caused significant damage to buildings and structures, as well as concomitant injuries and loss of life. In the last millennium, destructive earthquakes have occurred, on average, twice every century.

During the last few decades, activity of seismological research in Iceland has been steadily increasing. This activity includes earthquake monitoring programmes and a variety of research projects in geophysics, engineering seismology and earthquake engineering. The objective of this paper is to describe strong-motion monitoring and accelerometric recordings in Iceland and to point out the basic tectonic regime governing earthquakes in and around Iceland. The data available and information regarding its accessibility is outlined. Special attention is given to the Icelandic Strong Motion Network (IceSMN), which is operated by the Earthquake Engineering Research Centre (EERC) of the University of Iceland. The recordings obtained will be summarised, the data processing discussed and the interpretation of the data outlined.

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Iceland is the largest island on the Mid-Atlantic Ridge, which marks the boundary between the Eurasian and North American plates in the North Atlantic and between the South American and African plates in the South Atlantic. As it transects the island, the ridge is shifted eastward through two major fracture zones, one in the south called the South Iceland Seismic Zone (SISZ), and another in the north called the Tjörnes Fracture Zone (TFZ), which extends far offshore. The upwelling of mantel plume under the island increases Iceland's geophysical complexity (Gudmundsson, 2007).

Earthquakes in Iceland may be divided into three main categories, reflecting their primary triggering mechanisms:

- Tectonic earthquakes are due to the relative movement of the North American and Eurasian plates. These are the largest earthquakes and may reach magnitude 7. These earthquakes possess significant destructive potential.
- Volcanic earthquakes are attributed to volcanic activity as the main trigger. These earthquakes are generally located in the vicinity of well-known volcanoes, and their magnitude rarely exceeds 6. This type of earthquake does not normally have any significant effect on man-made structures
- Geothermal earthquakes, usually not exceeding a magnitude of 3, are small tremors occurring quite frequently in high-temperature geothermal areas. They do not have any significant effect on engineered structures, but create annoyance and disturbance to exposed people.

In addition to these naturally-triggered earthquakes, man-made earthquakes should also be considered to give an accurate representation of earthquake activity in Iceland. They are assigned primarily to the activities of man, such as (i) geothermal energy production, (ii) filling of reservoirs, and (iii) rock blasting. In all cases to date, they have been relatively small and insignificant.

Tectonic earthquakes in Iceland are of two types: (i) interplate earthquakes, related directly to plate boundaries; and (ii) intraplate earthquakes, originating within the plates distinctly away from the plate boundaries. Interplate earthquakes in Iceland can be divided into two groups, depending on the place of origin. The first ground contains earthquakes that originate in the spreading zone between the plates, i.e. on the Mid-Atlantic Ridge. These earthquakes are rather small, with magnitudes that seldom exceed 5. Their source mechanism appears to be predominantly normal. The second group contains earthquakes that originate in the aforementioned fracture zones. These are the largest earthquakes in Iceland., They generally occur on shallow, north-south oriented, nearly-vertical faults with a strike-slip mechanism.

The left-lateral tectonic movement across the east-west striking faults associated with the Mid-Atlantic ridge in SISZ is not visible on the surface. It appears that this tectonic movement is accommodated by right-lateral co-seismic slip on a series of north-south striking faults. Existence of these faults is supported both by the geological evidence of surface traces and the north-south elongated shape of areas severely damaged during large historical earthquakes (Björnsson and Einarsson, 1974; Bergerat et al., 2011). In the northern seismic zone, seismic faults are mostly offshore. (Stefansson et al., 2008).

In Iceland, intraplate earthquakes are not as frequent as interplate earthquakes: in the twentieth century they have only been recorded in the western part of the country (Einarsson, 1991). The mechanism of these intraplate earthquakes seems to be complex.

Documentation of earthquakes in Iceland goes as far back as 1,000 years. The nature and effects of historical earthquakes in Iceland have been summarised in the pioneering work of Thoroddsen (1925). Despite some important research on historical seismicity in Iceland, a unified earthquake catalogue has never been published. Due to the lack of an 'official' earthquake catalogue, researchers have used different earthquake catalogues for different purposes (Icelandic Meteorological Office, 2004a; Stucchi et al., 2013; for further details, see also, SHEEC–SHARE European Earthquake Catalogue 1000-2006, http://www.emidius.eu/SHEEC/). Ambraseys and Sigbjörnsson (2000) have compiled the available public domain data on earthquakes in Iceland and given a uniform and comprehensive account of seismicity of the region. This includes a parametric earthquake catalogue that goes back to 1896. The catalogue contains surface-wave magnitudes calculated from teleseismic data. The geographical distribution of the epicentres of the events contained in the catalogue is shown in Figure 1, along with the main tectonic structures.

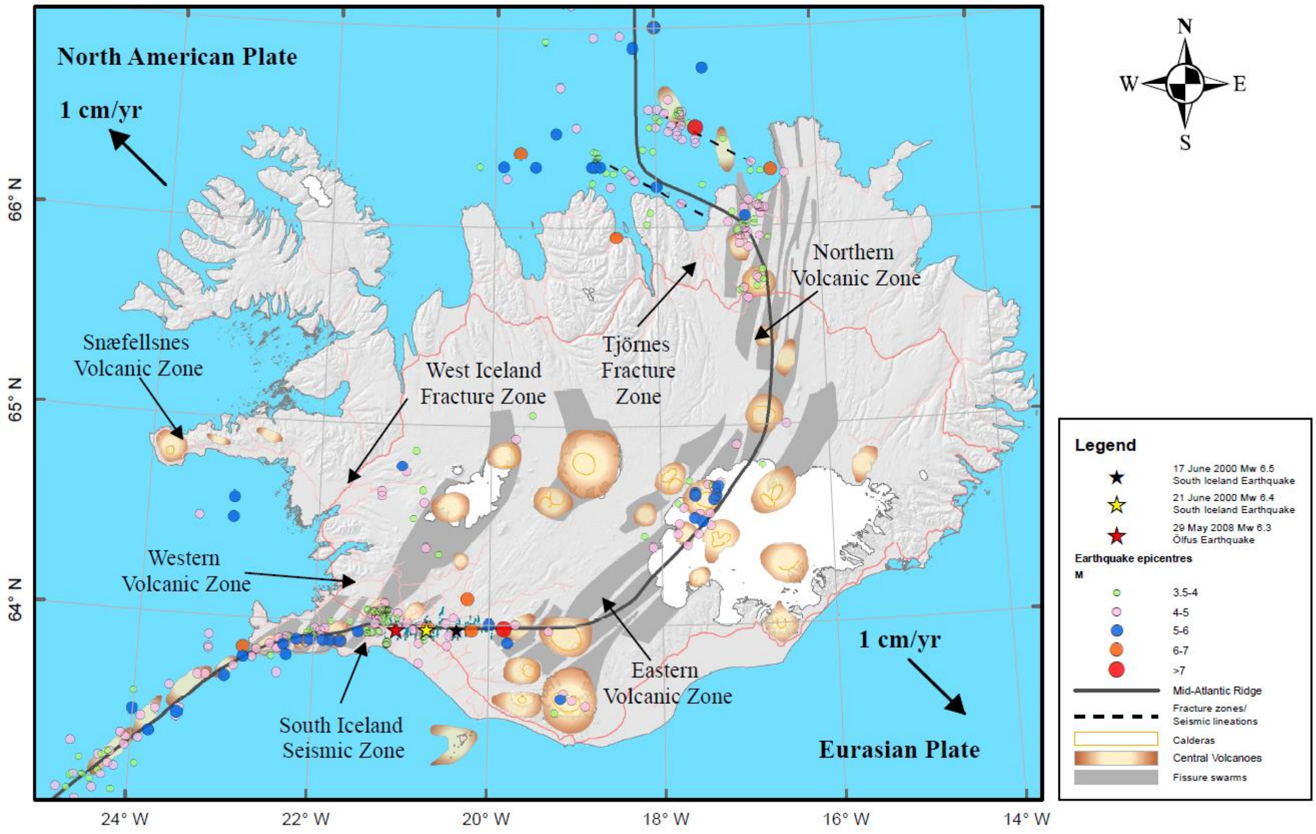

Figure 1. Main tectonic structures and earthquake epicentres. Orange areas denote Central Volcanoes. Grey areas denote volcanic zones as well as rift zones on land. Solid lines are offshore rift zones representing parts of the Mid-Atlantic Ridge. Dashed lines indicate fracture zones and seismic lineations. The grey curve crossing Iceland indicates the boundary between the North American and Eurasian Tectonic Plates. Circles and stars indicate earthquake epicentres.

## EARTHQUAKE MONITORING

The first instrument-recorded seismic event in Iceland is the destructive 1896 South Iceland earthquake sequence (Ambraseys and Sigbjörnsson, 2000; Sigbjörnsson and Rupakhety 2014). The first seismographic station in Iceland started operating in the beginning of the twentieth century. Since 1928 earthquake monitoring has been more or less continuous. Currently three earthquake-monitoring systems are permanently installed and operated in Iceland:

- The network of the Science Institute of the University of Iceland consists of about 30 seismometers, distributed throughout the country. The objective of this network was originally defined as scientific, primarily to facilitate tectonic and seismological research in Iceland.
- The SIL-system, which is operated by the Icelandic Meteorological Office (IMO). It consists of about 50 stations, each equipped with a tri-axial short period seismometer, connected to a central computer in Reykjavik (Icelandic Meteorological Office, 2004b). The primary purpose of the SIL-system has been defined in terms of earthquake prediction research. The seismic activity in Iceland can be viewed on-line using the website of the Icelandic Met Office: http://www.vedur.is.
- The Icelandic Strong-Motion Network (IceSMN) is operated by the Earthquake Engineering Research Centre of the University of Iceland. The objective of this network is primarily related to earthquake engineering research, with an emphasis on the dynamic behaviour of structures and infrastructure during earthquakes.

The Icelandic Strong-Motion Network was established in 1984. It started with a small-scale network proposed and installed by Professor Julius Sólnes in the early 1970s. The network has since steadily grown to its current size. The locations of the stations in the network are selected considering factors such as (i) seismo-tectonics and areas of highest seismic activity, (ii) geographic distribution of population, (iii) location of industrial premises and power plants, and (iv) location of main lifeline systems.

The Icelandic Strong-Motion Network consists of 34 ground response stations and arrays measuring ground motion and structural response. The geographical distribution of IceSMN stations is shown in Figure 2. Further details of the network are given in Table 1. At present, the network comprises of 185 channels, which can be divided as follows: (a) 22 standalone, tri-axial ground response stations in farmhouses and public buildings (66 channels); (b) three arrays in earth-fill dams (30 channels); (c) five arrays in hydro-power stations (58 channels); (d) two arrays in office buildings (14 channels); and (e) two arrays in seismically isolated bridges (17 channels). In most cases the sensors in ground response stations are located inside low-rise buildings. This is considered necessary due to severe climatic conditions. A disadvantage of such installation is the potential effect of building response on the recorded ground motion, which is of minor consequence for larger earthquakes. The network runs with a high degree of automation, using digital instruments. The individual stations and arrays are connected to a central computer that records detected events when the acceleration exceeds a prescribed threshold. The recorded data are stored in a database after routine signal processing operations are carried out on them.

In addition to the above mentioned strong-motion network, the Earthquake Engineering Research Centre also operates experimental strong-motion arrays named ICEARRAY (Halldorsson et al., 2009; Halldorsson and Avery, 2009).

## RECORDED AND PUBLISHED ACCELEROMETRIC DATA

Selected data recorded by the Icelandic Strong-Motion Network are freely available through the ISESD Website, http://www.ISESD.hi.is (Ambraseys et al., 2002). The information provided is: (i) raw data, i.e. uncorrected acceleration series; (ii) corrected acceleration series; (iii) derived time series; (iv) linear elastic response spectra; and (v) associated parameters, including earthquake magnitude, source-site distance metrics, site characterisation parameters, peak ground acceleration (PGA) and velocity (PGV), etc. Most of these data is also available on a CD-ROM which includes additional information such as non-linear earthquake response spectra (Ambraseys et al., 2004).

An overview of some Icelandic earthquakes, with magnitude exceeding 4, is given in Table 2. The triggering is in all cases by ground response channels. For these earthquakes, high-quality strong-motion records exist (Ambraseys et al., 2002). The list contains five earthquakes with magnitude close to 6 or higher. The first one of these earthquakes is the so-called Vatnafjöll Earthquake of 1985, which occurred near the eastern boundary of the South Iceland Seismic Zone. This was the first significant earthquake in the SISZ after the 1912 South Iceland Earthquake (Ólafsson, 1999; Ólafsson et al., 1998). In June 2000, the South Iceland Lowland was hit by a devastating earthquake sequence. The biggest events in this sequence were recorded on 17 June and 21 June (Sigbjörnsson and Ólafsson, 2004; Sigbjörnsson et al., 2007). During the sequence, approximately 80 earthquakes were recorded on the Icelandic Strong-Motion Network, resulting in about 750 ground response time series. These earthquakes were characterized by short duration and high peak accelerations (see Table 2). Furthermore, the recordings in the near-fault zone revealed typical directivity pulses which have been studied by Rupakhety (2010; see also Rupakhety et al., 2011).

The latest big earthquake in Table 2 is the Ölfus Earthquake (Halldorsson and Sigbjörnsson, 2009; Sigbjörnsson et al., 2009). This earthquake is of similar characteristics as the other earthquakes in the SISZ: short duration, high peak ground acceleration, and forward-directivity pulses in the near-fault zone.

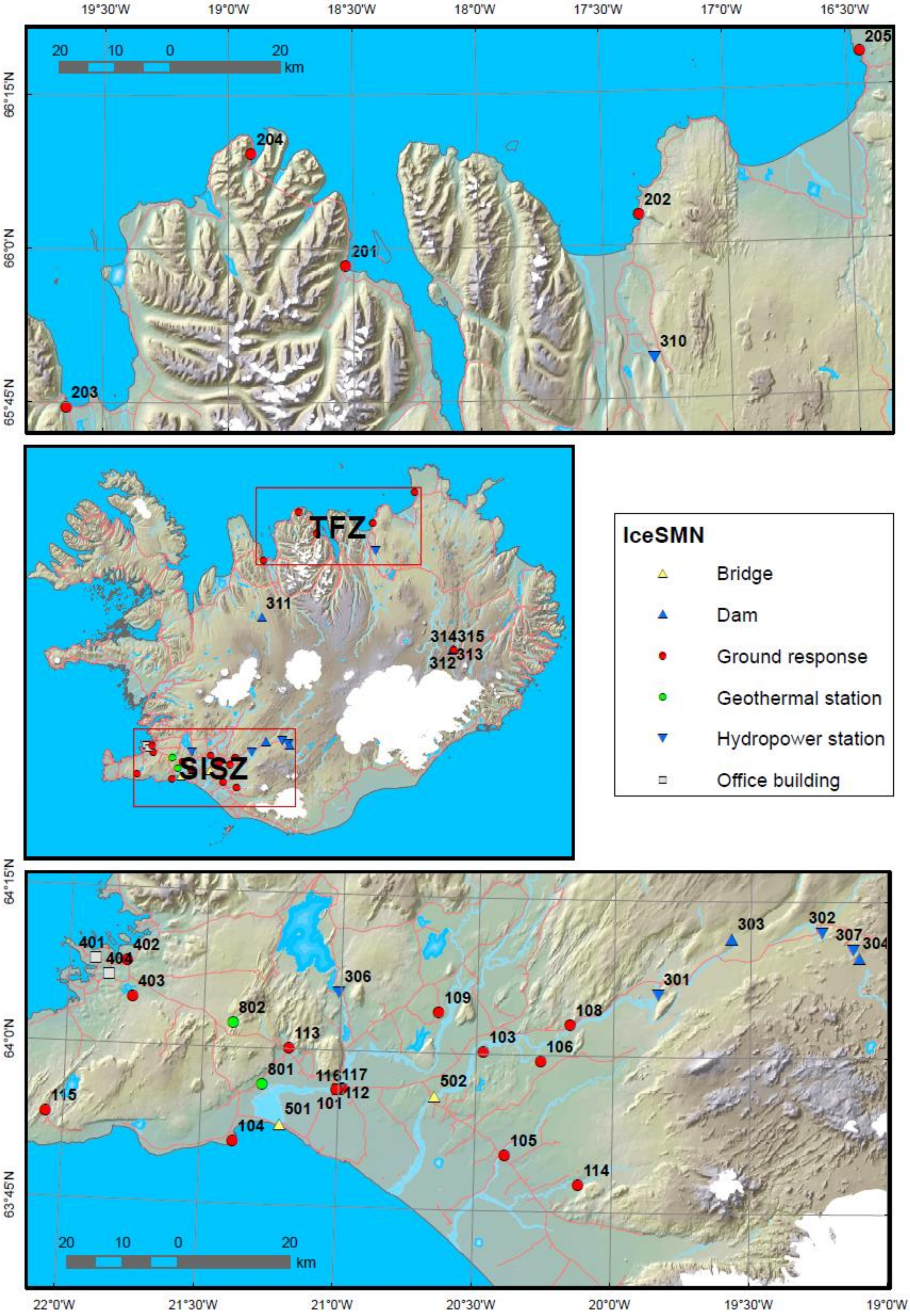

Figure 2. The Icelandic Strong-Motion Network consists of ground motion stations (red circles) and arrays in structures, including bridges, buildings, powerhouses and earth fill dams.

Table 1. List of ground response stations and arrays in buildings and structures of the IceSMN. Each ground response station contains a tri-axial sensor. The sensors are located in buildings or structures on firm ground.. The trigger thresholds are in the range 0.002 to 0.009 g, but are in most cases around 0.004 g. The types of stations are described as: FF – free field; SR – structure related free field; and DR – dam related free field.

| No | Site name | Location | | Instrument type | Structure | Type |
|---|---|---|---|---|---|---|
| | | °N | °W | | | |
| 100 | Reykjavík 7) | 64.14 | 21.96 | Kinemetrics SMA-1 | University building, 3 story | FF |
| 101 | Selfoss | 63.94 | 21.00 | CSI Cusp3C | Hospital, 3 story | FF |
| 102 | Hveragerdi 7) | 64.00 | 21.19 | Geotech A-700 | Church | FF |
| 103 | Kaldarholt 1) | 64.00 | 20.47 | Terra DCA-333 | Farmhouse, 2 story | FF |
| 104 | Thorlakshöfn | 63.85 | 21.38 | Kinemetrics ETNA | Office building, 2 story | FF |
| 105 | Hella 1) | 63.84 | 20.39 | Kinemetrics ETNA | School building, 2 story | FF |
| 106 | Flagbjarnarholt | 63.99 | 20.26 | Kinemetrics SSA-1 | Farmhouse, 2 story | FF |
| 107 | Thjorsartun 7) | 63.93 | 20.65 | Geotech A-700 | Farmhouse, 2 story | FF |
| 108 | Minni-Nupur | 64.05 | 20.16 | Kinemetrics ETNA | Farmhouse, 2 story | FF |
| 109 | Solheimar 1) | 64.07 | 20.64 | Kinemetrics ETNA | School building, 2 story | SR |
| 110 | Hvitarbakki 7) | 64.16 | 20.39 | Terra DCA-333 | Farmhouse, 1 story | FF |
| 111 | Selsund 1) 7) | 63.94 | 19.95 | Kinemetrics SMA-1 | Farmhouse, 1 story | SR |
| 112 | Selfoss, Radhus | 63.94 | 21.00 | Kinemetrics K2 (array)4) | Office building, 3 story | SR |
| 113 | Hveragerdi, Grund | 64.00 | 21.19 | CSI Cusp3C | Retirement home, 2 story | FF |
| 114 | Árgilsstadir | 63.79 | 20,11 | CSI Cusp3C | Farmhouse, 2 story | SR |
| 115 | Krýsuvík | 63,89 | 22.07 | CSI Cusp3C | School building 2 stories | SR |
| 116 | EERC | 63.93 | 21.00 | CSI Cusp3C | Office building, 2 story | SR |
| 117 | Selfoss, Church | 63.94 | 21.01 | CSI Cusp3C | Church with a tower | SR |
| 201 | Dalvik | 65.97 | 18.53 | Kinemetrics SSA-1 | Office building, 3 story | SR |
| 202 | Husavik | 66.05 | 17.36 | Kinemetrics K2 | Fire station, 3 story | SR |
| 203 | Saudarkrokur | 65.74 | 19.64 | Kinemetrics SSA-1 | School building, 2 story | FF |
| 204 | Siglufjörður | 66.16 | 18.91 | Kinemetrics SSA-1 | Retirement home, 3 story | FF |
| 205 | Kopasker | 66.30 | 16.44 | Kinemetrics SSA-1 | Residential house, 1 story | FF |
| 301 | Burfellsvirkjun | 64.10 | 19.84 | Kinemetrics K2 (array)6) | Hydroelectric power station | SR |
| 302 | Hrauneyjarfoss | 64.20 | 19.24 | Kinemetrics K2 (array)4) | Hydroelectric power station | FF |
| 303 | Sultartangastifla | 64.19 | 19.57 | HP/KMI (array)6) | Earth-fill dam | FF |
| 304 | Sigöldustifla | 64.16 | 19.10 | HP/KMI (array)4) | Earth-fill dam | SR |
| 305 | Irafossvirkjun 7) | 64.09 | 21.01 | Kinemet. SSA-1 (array)4) | Hydroelectric power station | SR |
| 306 | Ljosafossvirkjun | 64.10 | 21.01 | Kinemetrics K2 (array)5) | Hydroelectric power station | FF |
| 307 | Sigölduvirkjun | 64.17 | 19.13 | Kinemetrics K2 | Hydroelectric power station | FF |
| 309 | Sultartangavirkjun | 64.15 | 19.60 | Kinemetrics K2 (array)6) | Hydroelectric power station | SR |
| 310 | Laxarvirkjun | 65.82 | 17.31 | Kinemetrics SSA-1 | Hydroelectric power station | SR |
| 311 | Blöndustifla | 65.23 | 19.67 | Kinemet. SSA-1 (array)4) | Earth-fill dam | DR |
| 312 | Kárahnjúkadam | 64.95 | 15.79 | Kinemetrics K2 | Rock-fill dam | DR |
| 313 | Sauðárdalsdam | 64.94 | 15.82 | Kinemetrics K2 | Rock-fill dam | DR |
| 314 | Desjarárdam | 64.94 | 15.78 | Kinemetrics K2 | Rock-fill dam | DR |
| 315 | Kárahnjúkar | 64.94 | 15.79 | Kinemetrics K2 | Equipment house, 2 story | SR |
| 401 | Rvk., Hus Versl. | 64.13 | 21.90 | Kinemet. SSA-1 (array)4) | Office building, 14 story 2) | SR |
| 402 | Rvk., Foldaskoli | 64.13 | 21.79 | Kinemetrics SSA-1 | School building, 2 story | FF |
| 403 | Rvk., Heidmörk | 64.07 | 21.76 | Kinemetrics SSA-1 | Well-house/pump station | FF |
| 404 | Mjodd | 64.11 | 21.85 | CSI Cusp3C | Apartment building 14 stories | SR |
| 501 | Oseyrarbru | 63.88 | 21.21 | Kinemet. SSA-1 (array)4) | Concrete bridge 3) | SR |
| 502 | Thjorsarbru | 63.93 | 20.65 | Kinemetrics K2 (array)5) | Steel arch bridge 3) | SR |
| 801 | Bakki | 63.94 | 21.27 | Terra DCA-333 | Geothermal station, 1 story | SR |
| 802 | Hellisheiði | 64.03 | 21.45 | CSI Cusp3C | Geothermal power plant | SR |

1) Site-dependent magnification observed
2) Concrete shear walls
3) Bridge with seismic base isolation
4) Including one ground response station
5) Including two ground response stations
6) Including three ground response stations
7) No longer active but has recorded earthquakes

Table 2. Earthquakes recorded by the Icelandic Strong-Motion Network, for which good quality strong-motion records exist. All the listed records were triggered by ground response channels.

| Date | OT | Epicentre | | Magnitude[8] | | | | No[9] of | PGA[10] (m/s$^2$) | | | $D$[11] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (GMT) | °N | °W | $M_s$ | $M_w$ | $m_b$ | $M$ | records | $X$ | $Y$ | $Z$ | (km) |
| 26-Aug-1986 | 04:00 | 63.96 | 20.32 | | 4.6 | | 4.6 | 2 | 0.19 | 0.70 | 0.16 | 14 |
| 25-May-1987 | 11:32 | 63.91 | 19.79 | 5.95 | 6 | 5.7 | 5.9 | 7 | 0.60 | 0.51 | 0.53 | (24) |
| 09-Sep-1988 | 14:41 | 66.64 | 17.84 | 4.22 | 5.3 | 4.4 | 4.5 | 1 | 0.06 | 0.06 | 0.04 | 81 |
| 19-Mar-1990 | 10:47 | 63.95 | 21.93 | 4.68 | 4.7 | 4.8 | 4.7 | 3 | 0.10 | 0.13 | 0.07 | (16) |
| 30-Jan-1991 | 07:44 | 64.38 | 20.75 | 4.77 | 5.2 | 5.1 | 4.7 | 4 | 0.05 | 0.06 | 0.03 | (51) |
| 23-Apr-1991 | 10:27 | 63.99 | 20.39 | | 4.7 | | 4.6 | 3 | 1.05 | 1.21 | 1.07 | 4 |
| 27-Dec-1992 | 12:23 | 64.00 | 21.20 | 3.73 | 4.8 | 4.3 | 4.8 | 8 | 0.20 | 0.19 | 0.11 | (12) |
| 28-Aug-1993 | 19:59 | 65.97 | 17.94 | 4.1 | 4.6 | 4.2 | 4.6 | 3 | 0.22 | 0.38 | 0.14 | 27 |
| 08-Feb-1994 | 03:28 | 66.47 | 19.25 | 5.46 | 5.5 | 5.3 | 5.3 | 5 | 0.20 | 0.24 | 0.12 | 38 |
| 19-Aug-1994 | 19:19 | 64.03 | 21.25 | | 3.9 | | 3.7 | 2 | 0.04 | 0.03 | 0.01 | 26 |
| 20-Aug-1994 | 16:40 | 64.03 | 21.24 | 4.2 | 3.5 | 4.3 | 3.4 | 1 | 0.01 | 0.01 | 0.01 | 35 |
| 17-Jan-1996 | 18:02 | 66.01 | 18.13 | | 5.1 | | 4.3 | 2 | 0.20 | 0.18 | 0.06 | 19 |
| 14-Oct-1996 | 21:00 | 64.05 | 21.05 | 3.3 | 4.3 | 4.3 | 4.2 | 3 | 0.08 | 0.13 | 0.07 | 9 |
| 23-Feb-1997 | 08:45 | 63.94 | 22.08 | | | 4.0 | | 1 | 0.04 | 0.13 | 0.03 | 23 |
| 22-Jul-1997 | 16:22 | 66.29 | 18.39 | 4.6 | 5.0 | 4.7 | 5.0 | 2 | 0.13 | 0.26 | 0.08 | 36 |
| 22-Jul-1997 | 16:41 | 66.28 | 18.40 | | | 4.1 | | 1 | 0.04 | 0.07 | 0.03 | 35 |
| 24-Aug-1997 | 03:04 | 64.04 | 21.27 | 4.1 | 4.9 | 4.8 | 5.0 | 4 | 1.69 | 0.71 | 0.40 | 6 |
| 20-Sep-1997 | 15:38 | 66.26 | 18.33 | 3.7 | 4.8 | 4.5 | | 4 | 0.45 | 0.42 | 0.19 | 29 |
| 20-Sep-1997 | 15:52 | 66.23 | 18.30 | 4.2 | | 4.6 | | 5 | 0.56 | 0.48 | 0.30 | 31 |
| 03-Jun-1998 | 06:48 | 64.06 | 21.26 | 3.1 | | 4.2 | | 2 | 0.11 | 0.13 | 0.06 | 7 |
| 04-Jun-1998 | 19:05 | 64.04 | 21.28 | 3.9 | | 4.4 | | 6 | 0.39 | 0.35 | 0.16 | 7 |
| 04-Jun-1998 | 21:37 | 64.04 | 21.29 | 5.1 | 5.4 | 5.1 | 5.4 | 13 | 1.70 | 1.33 | 0.61 | 6 |
| 04-Jun-1998 | 23:00 | 63.99 | 21.30 | 3.9 | | 4.4 | | 10 | 0.57 | 0.53 | 0.30 | 6 |
| 13-Nov-1998 | 10:39 | 63.95 | 21.35 | 4.4 | 5.1 | 4.9 | 5.1 | 12 | 1.44 | 0.95 | 0.54 | 11 |
| 14-Nov-1998 | 14:24 | 63.96 | 21.24 | 4.2 | | 4.7 | | 9 | 1.43 | 2.31 | 0.96 | 5 |
| 25-May-1999 | 13:20 | 64.06 | 21.15 | 3.5 | | 4.2 | | 9 | 0.32 | 0.66 | 0.27 | 6 |
| 27-Sep-1999 | 16:01 | 63.98 | 20.79 | 3.6 | | 4.3 | 4.6 | 14 | 0.47 | 0.49 | 0.28 | 10 |
| 28-Sep-1999 | 21:50 | 63.98 | 20.79 | | | | (3.8) | 9 | 0.35 | 0.34 | 0.18 | 10 |
| 17-Jun-2000 | 15:41 | 63.97 | 20.36 | 6.6 | 6.5 | 5.7 | 6.6 | 26 | 6.14 | 5.02 | 6.54 | 7 |
| 17-Jun-2000 | 15:43 | 63.95 | 20.46 | | | 5.7 | 5.9 | 21 | 2.15 | 2.19 | 1.21 | 6 |
| 17-Jun-2000 | 15:45 | 63.90 | 22.13 | | | 4.9 | (4.6) | 3 | 0.10 | 0.04 | 0.05 | 27 |
| 17-Jun-2000 | 15:46 | 63.96 | 20.38 | | | | (4.4) | 9 | 0.84 | 0.40 | 0.31 | (6) |
| 17-Jun-2000 | 15:54 | 64.03 | 20.41 | | | | (3.7) | 9 | 0.70 | 0.46 | 0.48 | 4 |
| 17-Jun-2000 | 16:24 | 64.06 | 21.31 | | | | (3.6) | 5 | 0.14 | 0.19 | 0.07 | 9 |
| 17-Jun-2000 | 17:09 | 64.04 | 21.35 | | | 3.9 | 4.7 | 10 | 0.16 | 0.18 | 0.12 | 9 |
| 17-Jun-2000 | 17:40 | 63.98 | 20.72 | 4.4 | | 4.5 | 4.9 | 15 | 1.67 | 2.85 | 1.20 | 6 |
| 21-Jun-2000 | 00:52 | 63.97 | 20.71 | 6.6 | 6.4 | 6.1 | 6.5 | 26 | 7.30 | 8.22 | 4.14 | 5 |
| 21-Jun-2000 | 13:11 | 63.93 | 20.75 | | | | (3.4) | 8 | 0.32 | 0.36 | 0.20 | 5 |
| 25-Jun-2000 | 05:52 | 63.93 | 20.75 | | | | (3.5) | 8 | 0.35 | 0.39 | 0.25 | 5 |
| 01-Jul-2000 | 13:36 | 63.99 | 21.36 | | | | (3.6) | 5 | 0.10 | 0.12 | 0.05 | 9 |
| 18-Sep-2001 | 23:17 | 66.27 | 16.70 | | | 4.3 | (4.1) | 1 | 0.08 | 0.06 | 0.03 | 12 |
| 16-Sep-2002 | 18:48 | 66.93 | 18.41 | 5.7 | 5.8 | 5.5 | 5.7 | 6[12] | 0.10 | 0.08 | 0.05 | (89) |
| 23-Aug-2003 | 02:00 | 63.91 | 22.08 | 4.5 | 5.1 | 4.8 | 5.0 | 6[12] | 0.07 | 0.06 | 0.03 | 11 |
| 07-Jan-2004 | 23:25 | 64.02 | 21.22 | | | | (3.7) | 7[12] | 0.77 | 0.57 | 0.46 | 3 |
| 29-May-2008 | 15:45 | 63.98 | 21.13 | 6.3 | 6.3 | 6.0 | 6.2 | 20 | 8.77 | 8.93 | 5.07 | 2 |
| | | | | | | | Σ | 330 | | | | |

[8] $M_s$ refers to surface-wave magnitude, $M_w$ is moment magnitude (CMT) and $m_b$ is body wave magnitude (CMT), $M$ is the 'moment magnitude' assessed by the authors (see, for instance, Ólafsson, 1999), numbers in parenthesis represent $M_L$ published by the Icelandic Meteorological Office.

[9] Number of recording accelerometric stations in the network producing high quality tri-axial ground motion records (and additional structural response in the case of structural arrays).

[10] Peak ground acceleration at the station where the peak resultant acceleration is the largest.

[11] Distance of the closest station to the epicenter; placed inside parentheses when the station is different from the one whose peak resultant ground acceleration is reported in the table.

[12] The number includes stations where the peak ground acceleration was lower than 0.004g.

## DATA PROCESSING

As mentioned above, the recorded data from major earthquakes, along with the corrected and derived data are stored in the ISESD databank. The corrected records in the ISESD databank were obtained using a uniform processing procedure for majority of the records. No instrument correction was applied because many of the records were not associated with reliable instrument characteristics, which precluded the use of instrument correction techniques. This will only, however, affect the high frequencies in the record. An eighth order elliptical band-pass filter with cut-off frequencies of 0.25 and 25.00 Hz was used after a linear baseline had been fitted to the uncorrected acceleration time-history (Ambraseys et al., 2002). This filtering technique results in significant distortion of the response spectrum (see, for instance, Sigurdsson et al., 2012)

This processing method has some shortcomings and we recommend that the ISESD users process the data using more appropriate methods that fit their specific applications. To facilitate this, raw data is provided in the ISESD.

For high quality data recorded by digital instruments with high sampling rate an instrument correction of the accelerometric series is not needed for common engineering applications. Low-pass filtering should be carried out routinely with the cut-off frequency equal to or slightly lower than the Nyquist frequency. Adjustment (or baseline correction) of the raw data records is, however, needed. The adjustment scheme applied currently is described in Rupakhety et al. (2011) and Sigurdsson et al. (2012). These two publications deal with adjustment of near-fault records and far-field records, respectively. The adjustment scheme results in finite displacements in the near-fault zone and zero displacements in the far-field zone. An alternative adjustment scheme is proposed and applied by Chanerley et al., 2013). The above mentioned scheme by Rupakhety et al. (2011) is on the other hand found more robust and is therefore recommended and applied for routine processing of near-fault records.

In addition to the strong-motion parameters given in ISESD a special emphasis is placed on quantities that are invariant to coordinate transformations, sometimes referred to as rotational invariants (see Rupakhety and Sigbjörnsson, 2013; Rupakhety and Sigbjörnsson, 2014).

## DISCUSSIONON GEOLOGY

A basic knowledge of the geology of South Iceland Lowland is needed for the interpretation of the strong-motion data. The surface geology was mostly formed during and after the last ice age and consists of a pile of basaltic lavas, as well as tuff layers, often with intermediate layers of sediments or alluvium. The youngest lavas are from the Holocene (not more than 200 years old), while the oldest formations are up to 3.3 Myr old. During glacial periods Iceland was covered with a plateau glacier.

During warmer interglacial periods the ice melted and the glaciers retreated, which resulted in sea level changes up to 200 m. The South Iceland Lowland was then partly a seabed, accumulating marine sediments. During warm periods and towards the end of the Pleistocene, when the glaciers were retreating and the land was undergoing iso-static rebound, glacial streams formed thick sediment layers, composed chiefly of sand and fine-grained gravel. In the postglacial period, some of these sediments were covered by lava, which adds to the complexity of the geological structure of the surface. The lava layers may be as thick as 10 m while the sediment layers can be up to 20 m thick or even more. The shear wave velocity in basaltic rock is typically in the range of 2-2.8 km/s, depending on how dense the rock is, whilst the shear wave velocity is, on average, 850 m/s in tuff and 1,000 m/s in sedimentary rock.

The complexity of the surface geology characterised by the lava piles, tuff and sedimentary formations, is augmented further by fractures, fissures and faults of tectonic origin (Angelier et al., 2008, Bergerat et al., 2011). These intricacies tend to increase earthquake-induced effects as already noticed in the 1896 destructive earthquakes (Thoroddsen, 1925).

The ground response stations have been classified according to the Eurocode 8 classification scheme. The majority of the stations fall into the rock class ($v_{s,30} > 750$ m/s) leaving only two stations (109 and 111) in the stiff soil class (360 m/s $< v_{s,30} <$ 750 m/s). This classification should, however, be treated with some caution due to the inherent complex geological structure outlined above. Further studies into the classification of station geology are therefore in progress.

## CONCLUSIONS

Iceland, located on the Mid-Atlantic Ridge, is a seismically active area producing moderate sized to strong earthquakes. There are two transform zones where most of the significant earthquakes occur: the SISZ, which is located in a populated area; and the TFZ in North Iceland, which is mainly located offshore. The SISZ is currently relatively well instrumented, with networks comprising of sensors for various geophysical and strong-motion measurements. Earthquakes in the two zones are typically rather shallow and have, in most cases, a strike-slip mechanism. The Icelandic Strong-Motion Network has been in operation in both the SISZ and the TFZ since the mid-eighties. Strong-motion accelerations from several moderate sized earthquakes have been recorded during that period. The most notable events are the magnitude 6 Vatnafjöll earthquake on 25 May 1987 and the magnitude 6.5 South Iceland earthquakes on 17 and 21 June 2000. During the June 2000 events several high-quality ground acceleration records, as well as structural response records, were obtained, including many near-field records with very high PGA values. The records provide important information for earthquake risk mitigation, providing a basis for improved codes of practice and realistic seismic design actions. Records obtained in the Icelandic Strong-Motion Network, above magnitude 4, are now freely available through the ISESD website, http://www.ISESD.hi.is.

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