Iceland – Safety from Natural Hazards

Extract from Key Findings from a Hazard Assessment for Potential Sites for New Data Centers

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Please note that the following document is an extract only. To get further information please contact Invest in Iceland
Introduction

Iceland’s resources of renewable energy are due to the country’s location on the Mid-Atlantic Ridge. For some this blessing also raises the question of natural hazards related to geological activity, especially earthquakes. Experience, careful planning and scientific research has enabled generations of Icelanders to harness the valuable forces of nature while maintaining a secure and reliable electricity production, transmission system and communications network. The geologically active zone is relatively limited and earthquakes are not expected to cause significant damage to modern building and businesses. The volcanic eruption in Eyjafjallajökull in 2010 gained worldwide attention due to its effect on the international air traffic but it did not interrupt businesses in Iceland except the air traffic and the farming in the immediate vicinity of the volcano. The electrical power production and transmission as well as telecommunication were uninterrupted.

Natural hazards are of concern to many businesses reliable information regarding hazard assessment is important for decision makers. Recent events confirm that thunderstorms, hurricanes, tornadoes, wildfires, heat waves and large tsunamis can have severe negative effects on businesses relying on energy and/or data transmission. Fortunately Iceland is safe from these common forms of natural hazards. But since possible geological hazards are so vivid in many peoples minds Invest in Iceland commissioned Engineering and Consulting firm Verkís to carry out a detailed natural hazard assessment, focusing on a number of potential industrial sites, especially suited for Data Centers which are sensitive to any disruptions of services.

In June 2012 Verkís’ delivered the finished report titled “Hazard Assessment, Potential sites for new Data Centers”. Following are the main findings of the detailed hazard assessment. The report focuses on earthquakes and volcanic eruptions and contains references to the results of a number of research projects and monitoring of natural hazards. The full report is available upon request.

Main findings of the hazard assessment

The main natural hazards in Iceland are earthquakes and volcanic eruptions. The proposed industrial sites are all situated outside or on the edge of the immediate earthquake and volcanically active zones. Modern buildings are designed and constructed to withstand earthquakes. Limited effects of airborne ashes due to a volcanic eruption can be expected on all potential sites calling for actions concerning air filtering. In general the hazard effect reduces with distance from the active zones. The Icelandic infrastructure is well developed, electric and telecommunication systems are redundant and major utility companies have their response plans in place. International air traffic can be affected by airborne ashes from volcanic eruptions anywhere in the world, as previous events have shown and parties are becoming better equipped to respond and relocate services. Research on the effect of airborne ashes on aircrafts is developing making way for new regulations decreasing the disruption time. Recent natural events in Iceland disrupted businesses in the immediate hazard zones; country wide effect on business continuity was none. Larger events are possible within the next couple of hundred years, but are not considered to propose an immediate threat to businesses outside the active zones. It is therefore concluded that natural hazards should not propose an obstacle to situating a Data Center in Iceland.
Natural hazard research in Iceland

In Iceland a great number of research projects on natural hazards have been carried out and monitoring systems for seismic movements have been installed for the last decades. The Icelandic Meteorological Office (IMO) has the responsibility of monitoring natural hazards in Iceland and conducting research in related fields, as well as participating in international monitoring and research. The main research focus of the IMO is on earthquake and volcanic processes and hazards, glacial studies, ice-volcano interaction and climate change. IMO also focuses on research in multiparameter geophysical monitoring to develop better forecasts of hazardous events. Additionally, the IMO are responsible for avalanche warnings and hazard zoning. In addition several other institutions are involved in natural hazard research, including the Universities and earthquake institutions.

Earthquakes

The Reykjanes ridge (south west of Iceland) and Kolbeinseyjar ridge (north of Iceland) form a part of the North Atlantic ridge. The seismicity in Iceland is related to the Mid-Atlantic plate boundary which crosses the country. Within the country, the boundary shifts eastwards in the South and back towards the west in North Iceland through two fracture zones. The southern zone, called the South Iceland Seismic Zone (SISZ), is located in the South Iceland lowland. The Tjörnes Fracture Zone (NISZ) lies mostly off the northern coast of Iceland.

Through historical times seismic activity has been observed and reported. Moderate to strong earthquakes have occurred within the seismic zones. Major earthquakes of the order encountered at the Pacific plate boundaries (i.e. California), however, are unlikely to take place in Iceland. The maximum possible magnitude is estimated to be around 7 Mw for both zones; this upper bound is caused by relatively low rock strength and thin crust in the earthquake zones.

Probabilistic Seismic Hazard Assessment (PSHA) is practiced all over the world to estimate the seismic character of a region. These assessments estimate the earthquake intensity, e.g. peak ground acceleration, in a given region during a specific length of time. In Iceland several seismic hazards assessments exist.

Design of structural and non-structural systems of buildings for earthquake resistance is generally based on information about the site specific peak ground acceleration (PGA). Design of buildings in Iceland for earthquake resistance is based on the European building standard, Eurocode 8 and the site specific ground acceleration.
The figure below shows the horizontal reference acceleration (PGA) for earthquakes in Iceland according to Eurocode 8, with respect to the design working life of an industrial building (i.e. a data center). The blue circles are superimposed, showing the potential sites for Data Centers.

In general, industrial buildings, appropriate for Data Centers, can be designed according to the building code to withstand any expected seismic load in Iceland (including the main earthquake zones SISZ and NISZ). All the discussed sites for a Data Center are located outside the main earthquake zones where significantly less earthquake intensity is expected. Maximum possible earthquakes in Iceland (upper bound about 7 Mw within the seismic zones) are not expected to occur close to any of the potential sites.

For comparison the next figure shows a similar map for the United States. The dark green colored areas (0.10 g) in the Icelandic map are similar to the cyan and green areas on the US map. The comparison shows that earthquake intensity at the potential sites in Iceland are significantly less than should be expected in most part of California or in the state boundary of Missouri and Tennessee, in the New Madrid fault region.
Volcanic Hazard

Over the last 100 years several volcanic eruptions have occurred in Iceland but only one of them, the volcanic eruption in the Vestman Islands in 1973, has caused notable damage to structures or businesses since the volcano erupted right beside the town of Heimaey.

The best known eruption is probably the one in Eyjafjallajökull which started on April 14th 2010 and lasted till May 22nd. Although medium sized by Icelandic standards, the Eyjafjallajökull eruption soon became a global event and caused the cancellation of over 100,000 flights in Europe. The first days of the eruption while the air traffic in Europe was severely disrupted the air traffic in Iceland went on as normal. The international airports in Iceland were only closed for a few hours simultaneously during the eruption. Most airlines and aviation authorities were taken by surprise and were unprepared to meet the challenges of the situation. Since then air traffic authorities and airlines have revised and rewritten their response plans and are better equipped for response if needed. The event also triggered intense research on the effect and distribution of airborne ashes.

The local effect was limited. The tephra did neither cause disruption of electrical energy transmission or distribution, nor did it interrupt telecommunication. The fiber optical telecommunication cable on land was damaged when the main highway was cut through but communications were rerouted without disruptions due to net redundancy. No disruption was on the telecommunication to other countries. No disruption was experienced in the production of electrical energy by the hydropower stations in the country.

Flood barriers held against the three glacial floods that followed. The local road remained closed for four days but an emergency route allowed limited traffic during that time. Tephra fall-out, however, caused damages to nearby farmland and minor damages to nearby farms.

On May 21st 2011 the largest eruption in Iceland for the last decades began in Grímsvötn (sub-glacial lakes) in the North West side of the Vatnajökull icecap in the South East part of Iceland. Grímsvötn is the most active volcano in Iceland at present, with its last eruption in 2004. The eruption lasted until the 26th of May. The volume of tephra produced during the first days of the short lived eruption is estimated to have exceeded that of the first days of Eyjafjallajökull in 2010. It caused little damages to nearby farms such as to metal cladding and floor finishing, but caused damages to grown land.

Much less disruption was experienced in domestic and international air traffic due to the airborne ashes from the eruption in 2011 than in 2010. Airports in Iceland were partly closed down, some domestic flights were cancelled and international flights delayed. No disruption was experienced in the electrical transmission and distribution, electricity production or in the telecommunication system. Since the eruption did not cause a jökulhlaup it did not damage the main highway, though it was closed temporarily because of poor visibility.

All the potential sites for Data Centers are located outside the volcanic zones in Iceland, except Hafnarfjörður and Keflavík (two of the three sites in the South West part of Iceland) which are at the outskirts of the volcanic zone in the Reykjanes Peninsula. However, probability of damage or business interruption there is low. The two sites in the West and three sites in the North are all located quite far away from the main volcanic zones.

Other hazards

Other types of more site specific natural hazards include weather related events, avalanches, ocean and river floods, and the occurrence of sea ice.

These other hazards are not discussed in details in this report since they are in general more dependent on the exact location of the site in question.

Fortunately, Iceland is rid of many of the natural hazards threatening businesses in other countries, for example the USA, such as hurricanes, heat waves, droughts, wildfires and large tsunamis.
The Potential Sites Assessed

The potential sites proposed are in the South Western, Western and Northern parts of Iceland.

The three sites in the South West are all near the capital (metropolitan) area of Reykjavik, the sites in the West are in short driving distance from the capital area (40-80km) and the two sites in the North are situated relatively close to Akureyri, Iceland’s largest town outside the capital area.

All the sites have well developed infrastructure, are all connected to international air traffic, telecommunication and electrical power transmission. They are outside of the volcanic and earthquake zones, except Hafnarfjörður and Keflavík in Reykjavík-Reykjaness area.
South West Iceland

The South West part of Iceland has the highest population density and is the capital area, center of industry, administration, commerce, culture and education. The sites in the South West are within one hour’s drive from the international airport in Keflavík.

Landsnet’s circular 220 kV power transmission grid has a concentration area in the South West feeding the power intensive industry already in the area.

Other hazards than earthquakes and volcanic eruptions are not considered to influence the potential sites in South-West Iceland.

Reykjavík

Earthquake activity has been reported in the area but no major earthquakes have occurred. According to the earthquake catalogue dated back to the year 1700, a 6.3 and 6.0 Mw earthquakes occurred about 30 km south east of the area, in 1929 and 1968 respectively, causing little or no damage to buildings at that time. Maximum sized possible earthquakes in Iceland originate within the SISZ and NISZ (about 7 Mw) and are not expected to occur close to the area.

The horizontal reference acceleration (PGA) for earthquakes according to Eurocode 8, with respect to the design working life of a Data Center building in Reykjavík is low, or about 8% g. For comparison, the figure belows shows PGA and return periods in 9 cities in the US. Of those cities, the highest PGA value (475 year return period) is about 55% g in San Francisco and lowest about 15% g in Memphis and Sacramento. Reykjavík and all the following other potential sites in Iceland have lower PGA values.

The Reykjavik area is located outside the margins of the active volcanic zones, and the occurrence of volcanic eruptions within the area is considered remote.

**Keflavik**

Keflavik is a town of around 13,000 inhabitants, in the immediate vicinity of the Keflavik international airport. The town has a harbor for fishing vessels, cargo and cruisers and a large freight harbor in Helguvík. Special industrial sites outside of the town have been developed. The town is well connected to the rest of the area through the national highway system. One Data Center is located in the Keflavik airport area.

Despite of relatively high seismic activity, the earthquake hazard for this site is in general low. The horizontal reference acceleration (PGA) for earthquakes according to Eurocode 8, with respect to the design working life of a Data Center building in Keflavik airport area is low, or about 10% g, which is somewhat lower than in the earlier mentioned US cities.

Keflavik is located outside and west of the volcanic zone. Eruptions during the Holocene (the last 11,500 years) have not produced lava flowing into Keflavík. The occurrence of volcanic eruptions in the town is considered remote. Furthermore the Keflavik airport area is at somewhat higher altitude than the surrounding area which further reduces the probability of lava flowing into the area.
In recent years a heavy industry site has been developed in West Iceland, in proximity to the capital area, in Grundartangi at the mouth of Hvalseyri. Other parts of the area are rural farming areas with two small towns, Akranes and Borgarnes. Due to the heavy industry several power lines of the power grid run through the area. The sites in the West are within about one and a half hour’s drive from the international airport in Keflavik. The area is well situated with respect to the electric transmission grid.

Other hazards than earthquakes and volcanic eruptions are not considered to influence the potential sites in West Iceland.

**Grundartangi/Borgarnes**

Borgarnes is a small town of around 2,000 inhabitants in the West of Iceland. It is a center of services and administration for the surrounding farming area. It is well connected by road as the national highway runs through the town. In recent decades the town has developed an extensive industrial area. The small harbor in Borgarnes is solely for recreational and small fishing vessels.

Grundartangi is an industrial area in the fjord Hvalseyri 50 km from the capital area. Among other companies the Elkem Iceland and the Norðurál aluminum smelter are located in Grundartangi. The harbor at Grundartangi is used for heavy cargo connected to the industry.

The Grundartangi/Borgarnes area is located outside the active seismic zones of Iceland. The horizontal reference acceleration (PGA) for earthquakes according to Eurocode 8, with respect to the design work life of a Data Center building in Grundartangi/Borgarnes is low, or about 9% g.

The area is located outside of the active volcanic zones and occurrences of volcanic eruptions in the area are remote.
North Iceland

The northern part of Iceland is well connected to traffic through to the main highway. The international airport in Akureyri serves as an excellent connection for international and domestic flights. The area is well connected to both electrical transmission and telecommunication. Hydro power and geothermal power stations are located in the area (Blanda in western part and Krafla near Lake Mývatn in eastern part). Plans are for further geothermal power stations in the Mývatn area. The biggest town in the area is Akureyri with around 18,500 inhabitants.

The sites in the North are connected to air traffic through the airport in Akureyri (which can serve as an international airport), within an hour’s flight from the airports in Keflavík and Reykjavík. Sauðárkrókur and Blönduós are within an hour’s flight from Reykjavík.

Other hazards than earthquakes and volcanic eruptions are not considered to influence the potential sites in North Iceland.

Blönduós

Blönduós is a small town of about 900 inhabitants at the main highway, less than 2 hour’s drive from Akureyri. It is located at the mouth of the glacial river Blanda which is harnessed for production of electrical energy. The town is a service center for the surrounding agricultural area. The town has a small fishing harbor and an airstrip.

Blönduós is located outside the active seismic zones of Iceland, over 100 km east of the NISZ. In general, earthquake hazard in Blönduós can be neglected, with respect to the structural design of a Data Center building.

The area is located outside of the active volcanic zones and occurrences of volcanic eruptions in the area are remote.

The glacial river Blanda cuts through the area. The river has been harnessed by the 150 MW Blanda hydroelectric power plant. A 57 km² reservoir is located upstream in the river and the discharge through the power plant is returned back into the Blanda river, upstream of the town Blönduós. The reservoir regulates the discharge in the river, now used for salmon fishing, downstream of the HEP.
A quarter of the Hofsjökull glacier drains into the Blanda river. No glacial floods are known from the glacier since it attained its current size, some 2,000 years. The frequency of eruptions leading to jökulhlaups into the Blanda river is considered remote or about 1/10,000 per year, based on known lava fields around the glacier.

Sauðárkrókur
Sauðárkrókur is a town of 2,600 inhabitants, located approximately 24 km from the main highway and about 1.5 hour’s drive from Akureyri. It is the service and administrative center for the surrounding area, with a large fishing harbor, diverse industries and a small airfield.

Sauðárkrókur is located outside the active seismic zones of Iceland, about 50-70 km east of the main NISZ. No major earthquakes have occurred within the area. In general, earthquake hazard in Sauðárkrókur could be neglected, with respect to the structural design of a Data Center building.

The area is located outside of the active volcanic zones and occurrences of volcanic eruptions in the area are remote.

The Héraðsvötn glacial rivers (East Héraðsvötn and West Héraðsvötn) originate in Vestari and Austari Jökulsá, which drain the area north of the Hofsjökull glacier. Frequency of eruptions under the glacier leading to glacial floods in to the Jökulsá rivers are estimated 1/5,000 per year, based on known locations of lava fields over the past 10,000 years. A precise selection of the site should prevent the remote threat of jökulhlaup in Sauðárkrókur.

Akureyri
Akureyri is the largest town outside the capital area with around 18,500 inhabitants. The town is connected with the main highway, an international airport and a large cargo harbor. Akureyri is considered the capital of the North, with a center of administration, commerce, and industry, as well as having the major cultural and educational institutes. In the vicinity there are well developed industrial sites.

Akureyri is located at the southern skirt of the NISZ. No major earthquakes have occurred within the area.

The horizontal reference acceleration (PGA) for earthquakes according to Eurocode 8, with respect to the design work life of a Data Center building in Akureyri is low, or about 9%.

The area is located outside of the active volcanic zones and occurrences of volcanic eruptions in the area are remote. The area is not threatened by glacial floods (jökulhlaup).
Land Use, Infrastructure and Effect of Natural Hazards

All construction of buildings and infrastructure is subject to planning by the rules of the Icelandic National Planning Agency and permission from the respective municipalities. In the land use planning the respective area is assessed for example with respect to natural hazards. Hazard zones are mapped and restrictions on land use of these areas are issued, so known hazardous zones are not included in possible development as industrial sites or residential areas.

Structural design

All buildings in Iceland are designed according to the Euro Codes; the European building standards and the associated National documents. The National documents include provisions regarding wind load, snow load and seismic load, based on local condition in Iceland. Furthermore the Icelandic Building Regulation gives provisions for limitation of deflection of buildings. Due to geological conditions, soil liquefaction can be neglected.

A structural system of steel would probably be the first choice for a Data Center building. In general steel structures can be designed according to the building standards to withstand any expected seismic load in Iceland (including the main earthquake zones SISZ and NISZ). Based on the requirements for non-structural components, the limitation of deflection is likely to be the main issue of the structural system design.

Concerning other natural hazards (such as avalanches and ocean and river floods), a reasonable selection of a site prevents problems regarding the structural system design, with respect to the design working life of any typical industrial building.

The Past Effect of Natural Hazards on Infrastructure

The effects of natural hazards for the last decades tend to be local rather than regional. From Landsnet’s performance reports it can be concluded that the earthquakes and volcanic eruptions in recent decades did not affect the performance of the transmission grid. Neither did they disturb the electrical power production nor on the services of the telecommunication systems. There was very little local damage to structures which did not affect the services as all necessary lines and networks remained up and running, and mitigating actions have been taken to prevent or reduce the risk of disruptions or damage during tephra fall-out.

Other events, such as earthquakes, glacial floods, strong winds or avalanches have had no effect on businesses in the proposed areas. Severe winter storms with icing of power lines have had local disrupting effect on power distribution in different parts of the country. A Data Center directly connected to the transmission system would not be affected by disturbances in the power distribution system.
Results

Even though natural events are common in Iceland, they do not normally disrupt everyday life and the operation of businesses. The natural hazards of the last decades have not affected the proposed sites. The main hazards that possibly will influence businesses in the potential sites are large earthquakes and volcanic eruptions. Their main influence is localized on the volcanic and seismic zones. The potential sites are outside those zones, with the exception of the Reykjanes Peninsula, and are therefore not vulnerable to such events. Other hazards, such as floods, avalanches and weather related hazards can be avoided by selection of a building site within any of the areas.

In the following, the locations of the proposed sites for Data Centers in the South West, West and North of Iceland are compared with regard to the recurrence and/or probability of those natural hazards. The effect of natural hazards on Icelandic infrastructure and businesses is summarized and conclusions are drawn about the feasibility of locating a Data Center in Iceland with regard to natural hazards.

Comparison of Sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Earthquakes (PGA % g)</th>
<th>Volcanic Hazards</th>
<th>Recurrence (per year)</th>
<th>Lava flow</th>
<th>Jökulhlaup</th>
</tr>
</thead>
<tbody>
<tr>
<td>South-West</td>
<td>Reykjavík W</td>
<td>8%</td>
<td>remote</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>South-West</td>
<td>Hafnarfjörður</td>
<td>14%</td>
<td>1/2,500</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>South-West</td>
<td>Keflavík</td>
<td>10%</td>
<td>remote</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>West</td>
<td>Grundartangi</td>
<td>9%</td>
<td>no</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>Blönduós</td>
<td>3%</td>
<td>no</td>
<td>1/10,000</td>
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</tr>
<tr>
<td>North</td>
<td>Sauðárkrókur</td>
<td>4%</td>
<td>no</td>
<td>1/5,000</td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>Akureyri</td>
<td>7%</td>
<td>no</td>
<td>no</td>
<td></td>
</tr>
</tbody>
</table>

For earthquake hazard, the table shows an estimation of peak ground acceleration (PGA) with a 475 year return period, equal to 10% probability of exceedance in 50 years. A return period of 475 years is the reference PGA for the design of structures for earthquake resistance, according to Eurocode 8 building standard. The highest PGA value is in Hafnarfjörður, about 14% g and lowest in Blönduós, about 3% g. For comparison this report contains a figure that shows PGA and return periods in nine cities in the US. Of those cities, the highest PGA value is about 55% g in San Francisco and lowest about 15% g in Memphis and Sacramento.

The probability of structural damage or interruption of business and infrastructure due to earthquakes is therefore low for all the potential sites.

The areas in the West (Borgarnes, Grundartangi) and North (Blönduós, Sauðárkrókur, Akureyri), are located outside of the active volcanic zones and at distances greater than 70 – 80 km away from potential eruptions. The areas are not threatened by lava flow, major tephra fall-out or poisoning due to volcanic gases.

The Reykjanes-Reykjavík area is located at or at the edge of the volcanic active Reykjanes Peninsula. Hafnarfjörður is located on the outskirts of the system. Probability of recurrence of lava flow in Hafnarfjörður is estimated 1/2,500 per year.

All the potential sites are outside the main tephra fall-out areas from eruptions. In recent eruptions (2010 and 2011) the tephra fall-out was observed to be localized to the South East part of Iceland where the most volcanic activities occurs. The effect on businesses caused by tephra fall-out can
be reduced or prevented by active mitigation and response. By large explosive eruptions temporary disruption to international air traffic may be expected as observed in 2010 and 2011.

Conclusions

From this analysis it is obvious that Iceland is rid of many of the natural hazards threatening businesses in other countries, for example the USA, such as hurricanes, heat waves, droughts, wildfires and large tsunamis.

Earthquakes and volcanic eruptions of the last decades have caused little damage and had no disrupting effect on the services of electric power transmission, power production or telecommunication in the country as a whole and no effect on local services for the potential sites.

It can also be concluded that the earthquakes are not expected to cause problems at the potential sites, due to appropriate design of structures. The estimated PGA for the sites is relatively low, especially compared with places like California.

Some influence of ash fall can be expected in all sites from distant volcanic eruptions (more than 80 km away). It can be minimized with appropriate planning and response.

The sites in the South West are on the edge of the volcanically active Reykjanes Peninsula. The Peninsula has been dormant for over 700 years, but is considered to become active in the next 200 years. The recurrence of a lava flow from eruptions in the Reykjanes peninsula into the Hafnarfjörður area is of the order 1/2,500 per year, but remote for Keflavík and Reykjavík. Analysis on the effects of moderate effusive eruptions on the Reykjanes Peninsula is ongoing and should be considered during specific site selection in the area.

The reoccurrence of jökulhlaups in the proposed areas in the North West is considered to be 1/10,000 to 1/5,000 in a year.

For the reasons stated above, the proposed sites in West and North Iceland are considered to be more preferable than the proposed sites in the South West with regards to natural hazards.

An overall conclusion of this report is that none of the potential sites discussed is imminently threatened by natural hazards in the working life of a Data Center.