The Earthquake Strong-motion and GPS array in Húsvík, North Iceland

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The TFZ is a ~120 km offset in the Mid-Atlantic Ridge that is spreading at a rate of about 2 cm/yr (e.g., Metzger and Jónsson 2014; Tibaldi et al. 2016, and references therein) (Fig. 1). Earthquakes occur mainly along two main seismic lineaments in the TFZ, the Húsvík-Flatey Fault (HFF) and the Grímsey Oblique Rift. The HFF is the largest transform fault in Iceland, extending over 100 km from Theistareykir fissure swarm in the east, through the town of Húsvík, and west to the Eyjafjarðaráll Rift. The town of Húsvík, North Iceland, is the second largest town in North Iceland (2,300 people) and is located directly on top of the HFF (Sæmundsson 1974). With its infrastructure and fast growing technical sector and heavy industries, the town of Húsvík is exposed to relatively high seismic risk.

Continuous GPS (CGPS) observations in the TFZ began in 1999 and by 2002 three CGPS stations were operating in the region. The network of CGPS instruments was significantly improved in 2006-7 and it now contains 14 stations, including stations positioned on a profile across the onland portion of the Húsvík-Flatey Fault (Fig. 2). The main purpose of the CGPS network is to monitor crustal movements and to provide detailed insight into the kinematics of the transform zone (Geirsson et al. 2006; Geirsson et al. 2007). The mostly offshore location of the TFZ and its complex tectonics make it challenging to resolve the transform kinematics and evaluate the seismic potential of the two main transform structures, the Grímsey Oblique Rift, and the Húsvík Flatey Fault. However, the network results show that currently the transform motion in the TFZ is currently accommodated ~34% by the HFF and ~66% by the GOR. The resulting slip velocity of ~6.9 mm/yr on the HFF and the time since the last two strong M6.5 earthquakes in 1872 indicate a slip deficit on the fault of ~0.83-1.05 meters, assuming a steady slip rate since 1872. This slip deficit corresponds to the seismic potential of the HFF being equal to ~M6.8 earthquake (Metzger et al. 2011) (the maximum considered earthquake potential of the western HFF is ~M7.3 (Björnsson et al. 2007)).

With Húsvík being the second largest town in North Iceland (2,300 people, Figs. 3) and located directly on top of the HFF (Sæmundsson 1974), it is exposed to relatively high seismic risk. Moreover, the local site conditions in Húsvík are in part characterized by soft sediments of varying depths and elevation differences (Fig. 3) depending on the location inside the town (Halldorsson et al. 2012; Waltl 2013). Buildings and critical infrastructure on and across such soft site conditions are much more susceptible to earthquake damage than infrastructure built on firm ground. This is supported by theoretical and empirical evidence in all damaging earthquakes since the dawn of
earthquake and geotechnical engineering and seismological monitoring (see e.g., Kawase 2003, and references therein).

The Icelandic Strong-motion Array (ICEARRAY II) is the first, dense and multidisciplinary instrumentation system monitoring tectonic movement and earthquake strong-motion in Iceland. It is located in Húsavík, North Iceland, traversing the town and the HFF (Fig. 2). The ICEARRAY II consists of several Trimble NetR9 Ti-1Global Navigation Satellite System (GNNS) instruments, with the extraordinary capabilities of recording its position at 50 samples per second. Equipped with a Zephyr Geodetic 2 antenna a NetR9 GPS instrument is collocated at three key strong-motion stations of ICEARRAY II. The strong-motion stations are equipped with Canterbury Seismic Instruments’s CUSP-3C three-component micro-electromechanical (MEM) accelerograph, having a wide dynamic range and 200 Hz sampling rate. The purpose is to monitor both slow (i.e. tectonic spreading) and fast (i.e., earthquakes) ground motion, and quantify their variabilities, not only across the HFF, but especially over the small urban area in terms of wave incoherence and localized site-amplification effects that the variable soil conditions and elevation differences in the area are likely to enhance (Fig. 3). Additionally, and in the event of a strong earthquake on the HFF, it is highly likely that it will involve permanent tectonic displacement of the ground in the near-fault region. In this case the collocated measurements of displacements and accelerations can provide a robust way of estimating the instrument’s respective capabilities of measuring displacements (strong-motion instruments) and accelerations (high sampling rate CGPS).

The ICEARRAY II generated, during the intense earthquake sequence in North Iceland in 2012-2013, the only dense urban measurements of earthquake strong-motion data in North Iceland. It recorded 24 of the largest earthquakes (up to $M_5.5$). The tentative analysis of the localized site-amplification effects and the spatial variability of strong-motion indicate variable earthquake hazard and seismic risk across the town. On the basis of strong-motion data in South Iceland, in particular on the dense urban array ICEARRAY I in Hveragerði, methods will be developed and tested before the application on the dataset of ICEARRAY II. That includes physical earthquake source models the strong-motion of which will be simulated for the Husavik greater area on the basis of hypothetical scenario earthquakes on the HFF fault, with emphasis on near-fault effects. The sensitivity of those simulations, coupled with the relative differences in ground motion amplitudes expected in the town of Húsavik, will be analysed and their reliability estimated. Such information will be utilized for the purpose of updating the earthquake hazard estimates for the Húsavik and the TFZ area. The combination of earthquake data and the models developed is expected to contribute to a new seismic risk map of Husavik, thereby improving the safety of the community and its resilience against damaging earthquakes.

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Figure 1. Tectonic situation of NE-Iceland. The seismically active Tjörnes Fracture Zone (TFZ) constitutes the northern offset of the Mid-Atlantic Ridge (MAR) on Iceland. The Húsavík–Flatey Fault (HFF) is the main transform fault with an overall right-lateral strike slip. The Grimsey Oblique Rift (GOR) and the much less active Dalvík Lineament (DL) are further tectonic lineaments in the TFZ. The yellow polygons represent rifting areas of the MAR: the fissure swarms of the Northern Volcanic Zone in the east and the Kolbeinsey Ridge in the west (Hjartadóttir et al. 2015). Red crossed dots mark important historical earthquakes (with year and magnitude; Stefánsson et al., 2008), gray-shaded dots indicate the location and strength of the 2012/13 earthquake swarms on the western ends of the HFF and GOR). Plot generated based on information and data from (Tibaldi et al. 2016) via pers. comm. with Ásta Rut Hjartardóttir).
Figure 2. A schematic map showing the distribution of CGPS stations (yellow squares) and strong-motion stations (black dots) and comprise the ICEARRAY II network. Where the strong-motion and GPS stations are collocated is shown with a black dot inside a yellow square. The red thick lines indicate the surface trace of the Husavík-Flatey Fault.
ICEARRAY II stations in Húsavík consist of free-field strong-motion stations (red triangles), collocated free-field CGPS and accelerometric instruments (yellow triangles) and structural CGPS and accelerometric station (yellow square). Elevation differences are highlighted by the coloring scheme used (from Waltl, 2013).