

# Chapter 15

## The Current State of Strong Motion Monitoring in Switzerland

J. Clinton, C. Cauzzi, D. Fäh, C. Michel, P. Zweifel, M. Olivieri, G. Cua, F. Haslinger, and D. Giardini

**Abstract** The next generation Swiss Strong Motion Network has recently been funded by the Swiss Government: in the next 8 years the Swiss Seismological Service expects to install 100 new 24-bit broadband freefield stations in predominantly urban locations across the country with realtime, continuous data transmission at high sampling rates. This infrastructure will compliment the existing 30 comparable realtime stations installed over the last 3 years, and replace the original ~70 strong triggered dial-up network installed in the early 1990s. The introduction of these new stations provides an opportunity to reassess how strong motion data is used in Switzerland, for routine network operations, emergency response and scientific purposes. The strong motion data will be acquired in parallel with the existing broadband network, and will be processed together with broadband data for earthquake early warning, triggering and locations, near real time ShakeMaps, and moment tensor inversion. Challenges arise on how to archive and provide this type of data to the scientific and engineering communities. Metadata maintenance needs to parallel efforts for the broadband network. Although permanent online archival of large volumes of data is rapidly becoming more affordable, this size of the new dataset dwarfs the existing broadband data currently being generated. We discuss the optimal strategies to permanently archive the continuous data, both within Switzerland, and via the existing European data infrastructures.

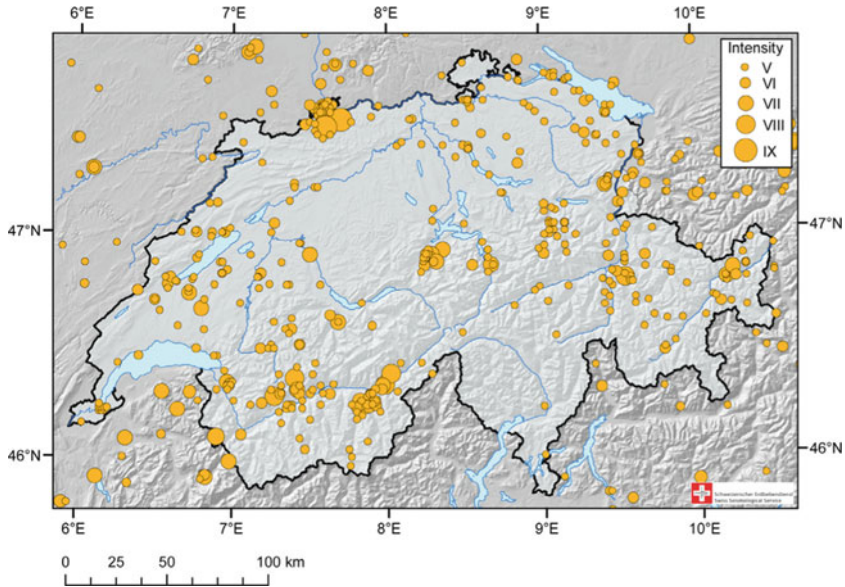
### 15.1 Introduction

When compared to seismically more active regions, damaging earthquakes are rare in Switzerland. Nevertheless, 10–15 earthquakes are felt (on average) each year by the population and damaging events are expected every 5–10 years [36]. Over the past 800 years, Switzerland has suffered at least 28 events with attributed moment magnitude  $M_w \geq 5.5$ , 12 of these resulted in severe damage to buildings, with macroseismic intensity values reaching or exceeding VIII [16]. The historical

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J. Clinton (✉)

Swiss Seismological Service (SED – ETHZ), Sonneggstrasse 5, 8092 Zürich, Switzerland  
e-mail: j.clinton@sed.ethz.ch



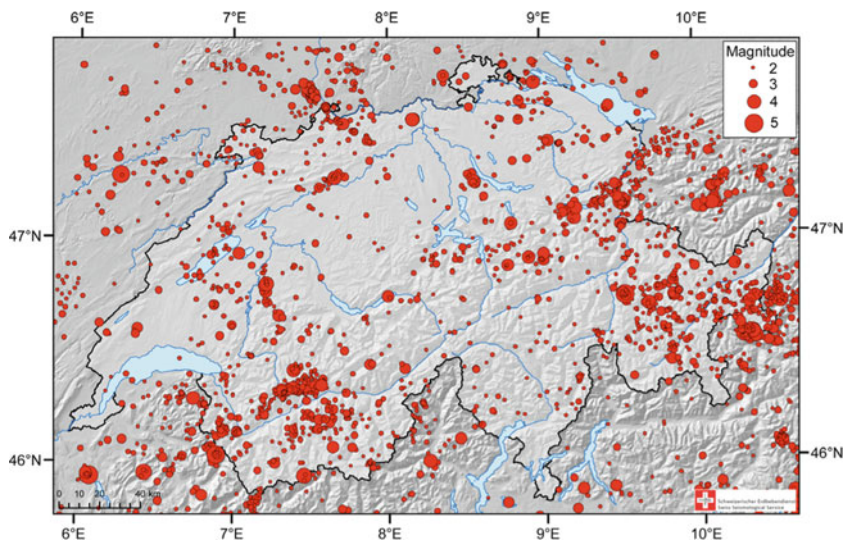
**Fig. 15.1** Historical seismicity in Switzerland between 250 and 1974. Only events with attributed intensity  $\geq$  V are shown. Symbols are proportional to macroseismic intensity. Note the high damaging historical earthquakes in the region of Basel (NW) and in the Wallis (SW)

seismicity distribution in Switzerland is depicted in Fig. 15.1. Seismic activity is highest in the Wallis (SW) and in the Basel region (NW). Central Switzerland, the Graubünden (SE), and the Rhine Valley of St. Gallen (NE) have also experienced significant shaking in the recorded history.

In spite of the moderate hazard level [36], a relatively high seismic risk exists in Switzerland [21], resulting from the (a) high population density, (b) high degree of industrialization, with critical infrastructures including dams, nuclear power and chemical plants, and (c) generally low level of preparedness due to the relatively long return periods of strong ground shaking.

Instrumental observations now complement the macroseismic observations and provide the basis for a homogeneous record of the seismicity in Switzerland since 1975. The instrumentally recorded earthquake catalogue in Fig. 15.2 shows close correlation with the macroseismic catalogue.

The Swiss Seismological Service (SED) at the ETH Zürich (ETH) is the Swiss federal agency responsible for monitoring the seismicity of Switzerland and surrounding areas, providing rapid notification of earthquakes to the local authorities and the public, and archiving and providing reliable data for seismological and earthquake engineering research studies. The SED manages both a high-gain broadband/short period seismometer network and a low-gain accelerograph network. The former is intended to monitor earthquake activity at magnitudes well below the human perception threshold [9], whereas the latter is principally aimed at engineering purposes and thus mainly records strong motion. Nevertheless, the



**Fig. 15.2** Instrumental Seismicity (1977–2009) in Switzerland observed by the SED. Over 25,000 events were located by the SED in this period

progressive introduction of broadband low gain accelerometric sensors with very large dynamic range alongside high-dynamic range dataloggers is rapidly blurring the boundary between weak and strong motion instruments – leading to digital ground velocity records of engineering significance and acceleration records of seismic observation quality.

## 15.2 Seismic Monitoring in Switzerland

Instrumental monitoring of earthquake activity in Switzerland began at the onset of the twentieth century. Since then Switzerland has been at the forefront of seismic monitoring in Europe. By the 1970s, a telemetered high-gain short-period seismic network was installed, with data recorded on microfilm support. By the mid 1980s, the network consisted of a dense network of high gain sensors with radio communications digitized on a central computer system and automatically processed. In the early 1990s, the initial National Strong Motion Network was established, with dial-up triggered instrumentation.

The modern Swiss Seismic Network was created in the late 1990s, when broadband sensors alongside 24-bit dataloggers replaced the short period sensors, GPS timing was introduced, and communications were upgraded to a high bandwidth, secure internet system. This new network is known as the CHNet, and comprises the national broadband (SDSNet) and the national strong motion (SSMNet) networks, as well as some Special Networks (targeted local densifications based on temporary projects).





The strong motion sensors are uniformly all EpiSensors, set to 2 g clip level, with ~155 dB dynamic range and flat frequency response from 200 Hz (above the Nyquist frequency at all sampling rates we use) to DC. The dataloggers, typically Nanometrics Taurus, are the current equivalent of the 24-bit SDSNet dataloggers.

Data from strong motion co-located with broadband are sampled at 120 sps, and at 250 sps at the standalone strong motion sites. Commercial ADSL lines are used for the standalone stations. Once the data reaches the SED, it is acquired, processed and archived in a similar manner to the broadband SDSNet stations.

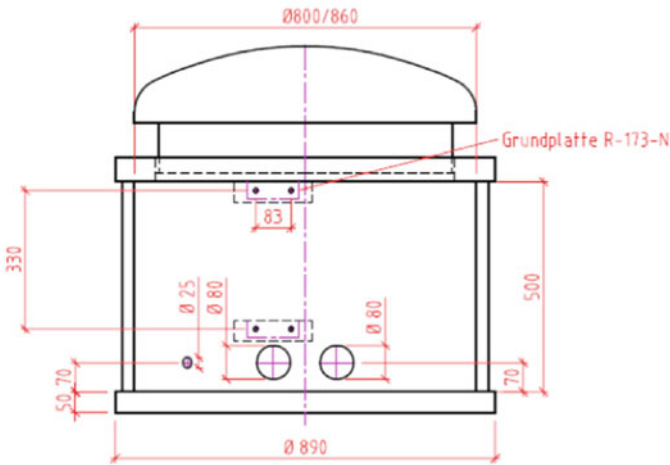
### ***15.2.4 Planned Strong Motion Network Upgrade***

The renewal of the Swiss Strong Motion Network was funded in 2009 by a decision of the Swiss Federal Council. The project involves installation of some 100 new accelerometer stations over the next 8 years, with an initial 30 new stations to be installed in the first 4 years. The key goal of the network is to densify instrumentation in the major Swiss cities and towns, in particular those with elevated seismic risk. Many of the dial-up stations will be upgraded. Instrumentation quality and communications will also be state-of-the-art, very broadband accelerometers with 24 bit digitization and real time continuous communication of high sample rate data. The data will also be processed alongside the SDSNet data. Site selection will accommodate both scientific objectives and the level of cultural noise in order to maximise usage of the collected data.

As part of the project, a new housing solution has been designed (Fig. 15.5) for the standard new station. This is an improvement over existing urban strong motion station installations, and will minimize the effects of cultural and electrical noise. The vault consists of a concrete cylinder with a metallic cover, and hosts the sensor. A separate casing with the datalogger and communication systems can be placed either inside the vault, or several meters away from the station. The vault is anchored to the ground via steel bars in order to avoiding ground settlement, relative displacements and rotations [22]. Each station will have a detailed geophysical site assessment.

## **15.3 Strong Motion Data Archival, Dissemination and Storage Considerations**

New strong motion stations at the SED are fully integrated into the Seismic Network. Data are collected at the SED in real-time (data latency is typically under 3 s) at high sampling rates, and passes through identical processing as broadband streams. This means if a strong motion station is considered quiet enough, it can be used for earthquake detection and automatic location. For manual event revisions, which are completed within tens of minutes following major events in Switzerland, all real-time strong motion streams are available, and often used, for both location



**Fig. 15.5** Station housing concept for new SSMNet stations – photo from prototype installation at SSMNet station SCEL. The accelerometer is stored within the concrete cylinder. The data logger and communication system (*orange casing*) can be hosted either in the same housing, or alternatively several meters away from the sensor

and magnitude estimates. Acquiring strong motion alongside our other datastreams also allows us to archive strong motion data identically to the broadband data, and to take advantage of the software created to optimise the quality and completeness of the waveform archives.

In nearly 20 years of operation so far, the SSMNet triggered dial-up network generated over 700 triggers that have been associated with earthquakes located by

the SED Seismic Network. The total volume of data recorded in this archive is 16 MB. The SED has been producing waveform event files of  $\sim 100$  s duration for all digital recordings of earthquakes since 1983, including short period, broadband, and strong motion data as available. The total volume of these over 25,000 event files is 48 GB. In contrast, a single continuous 250 sps channel recording requires approximately 30 Mb/day ( $\sim 11$  GB/year). Nevertheless, as data storage has become cheap, the SED now permanently archives all data collected by all stations within the CHNet, including the high sample rate continuous strong motion data. This has required a change in the approach the Network takes to data storage. The complete continuous waveform archives, dating back to late 1999 (the advent of broadband installations in the CHNet) are available on high availability rapid access disk that are maintained and backed up by professional IT group at the ETH. The archives are stored in both GSE2 format [24] and miniSEED format [33]. Currently, the complete archives of the CHNet in miniSEED format require 7 TB of disk space. The current growth of these archives is  $\sim 3$  GB/day ( $\sim 1.1$  TB/year), of which 70% of the total is due to the  $\sim 40$  strong motion stations.

For comparison, the entire ORFEUS Data Center (ODC) Archives, which archive broadband data from across Europe at until very recently at only lower 20 or 40 sps sampling rates, comprise 4 TB (Reinoud Sleeman, personal communication). GFZ and IRIS, who maintain international archives at higher sampling rates, have archive volumes of 30 TB (Andres Heinloo, personal communication) and 105 TB (Rick Benson, personal communication) respectively.

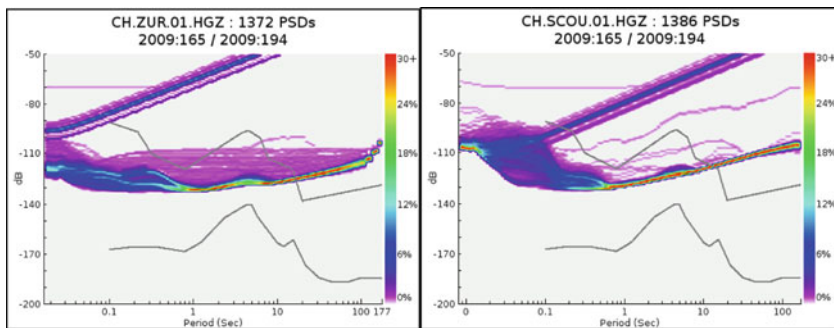
The SED has also been providing real-time strong motion waveforms to the ODC since mid-2009. These new streams, allied to a new ODC policy to begin archiving all seismic data at the highest available sampling rates rather than 20/40 sps, has lead to a dramatic rise in their daily archive growth rate, from under 3 GB/day to over 6 GB/day (Reinoud Sleeman, personal communication).

Beyond the ODC, the SED shares Swiss data with neighbouring seismic agencies (INGV, ZAMG, LED, BGR, GeoAzur Nice) and international agencies (IRIS/GFZ) over either an InterNaqs or SeedLink connection. Both ZAMG and the ODC have begun taking strong motion data feeds in realtime. We expect this sort of data sharing to grow as more and more agencies begin to operate continuous realtime strong motion stations, and become capable of processing this data in their own realtime seismic processing systems and event products (e.g. ShakeMaps).

In the past, the SSMNet triggered data has been made available on a dedicated web platform that was independent of the real-time continuous data streams. The continuous strong motion data was only available in event and continuous files on request. The SED now runs ArcLink [23], a software product from GFZ, which allows open access via scripting and web requests, to the entire continuous archives. The triggered data is added to this dataset.

The SED is an active contributor to the Accelerometric component of the European Earthquake Data Portal (<http://www.seismicportal.eu/> – last accessed 1 April 2010). This project, involving a core group of 6 Accelerometric Networks as well as the European Mediterranean Seismological Centre (EMSC), has created a freely available distributed strong motion archive [31] that can be searched using





**Fig. 15.6** Images from PQLX for 2 SSMNet stations at ZUR (collocated with STS2) and SCOU (standalone). The *grey lines* are the *high* and *low* noise models of Peterson [29]. The background signal at high frequencies is measuring the site noise. The microseismic peak is visible between 5 and 10 s. Between  $\sim 1$  and 5 s, and beyond 10 s, the background signal typically is recording the sensor/datalogger noise

station, event and waveform parameterisations (e.g. PGA, PGV, Housner Intensity). As the SED now operates continuous stations, we were able to contribute all records from ML2.5 irrespective of the PGA, and thus our contribution does not have a sampling bias.

The continuous strong motion stations are now routinely processed via the health monitoring software tool PQLX [28]. This software, a standard tool for the broadband community, calculates power spectral densities from the continuous data illustrated as a probability density function. The software allows evaluation and temporal tracking of background station noise across the frequency spectrum. From this tool, it is clear the typical SED high quality continuous strong motion station stays below the Peterson [29] High Noise Model from high frequencies ( $\sim 50$  Hz) to just beyond the microseism ( $\sim 15$  s). The microseismic peaks are observed at all stations, as are occasional large teleseismic events at longer period. We observe high frequency cultural signals at  $f > 1$  Hz, well above the sensor/datalogger noise at all sites except some of the best co-located sites in the SSMNet. Most stations record sensor noise rather than the background site noise only beyond the microseismic peak ( $T > 10$  s), except for a short frequency window between 1 s and the emergence of the microseismic peak ( $\sim 5$  s) (Fig. 15.6). This suggests that strong motion data from the new SSMNet can be applicable for use in future noise study investigations.

## 15.4 Use of Strong Motion Data at the SED: Network Products and Research

The 40 strong-motion channels acquired continuously in real-time at the SED are processed identically to the broadband and short-period sensors also monitored by the Seismic Network. This allows use of the strong motion data for routine automatic network operations, manual locations and seamless archival of continuous

data and extraction of data into event files. Metadata maintenance, and health monitoring – both of waveform completeness and waveform signal quality – are also kept to the same standards as the rest of the network. This ensures a high quality in strong motion network performance, and near 100% recovery of event data, a performance that is far above that the SED was able to reach with the dial-up strong motion network.

The easy access to high quality strong motion data in both continuous and event form allows researchers at the SED to use strong motion data for a variety of purposes.

### ***15.4.1 Earthquake Detection***

Most strong motion stations are located in urban sites and thus have high cultural noise, in particular in the 1–30 Hz frequency range suitable for local earthquake detection. Nonetheless, some stations are located at good sites on competent ground, and are included in the detection routine – this helps to locally improve the earthquake detection capacity of the network.

### ***15.4.2 Earthquake Locations and Local Magnitudes***

If a strong motion station contributes triggers to an event association, a P-pick will be searched for (using the Baer Picker [2]) and if found, the station will be included in the automatic location, though the magnitude will not be used. Once an automatic location is created, a single file is extracted for manual review containing all realtime waveforms monitored by the SED, including all the available strong motion stations. Manual locations, which are available within 10s of minutes following felt earthquakes in Switzerland (>ML2.5 inside the country), incorporate picks from strong motion stations wherever applicable. In 2009 about 10% of all reviewed earthquake picks were made on strong motion records, even though the great majority of events have magnitude below ML2.5. Although we can use the Wood Anderson amplitude for manual estimates of the Local Magnitude, due to poor signal-to-noise, this is typically only done when strong motion stations record events with  $ML > 3.5$ .

Dial-up strong motion data, if triggered, is manually added to the event files within hours/days of an event, and can also be used to refine manual locations and local magnitudes.

### ***15.4.3 ShakeMaps***

The SED produces USGS ShakeMaps [34] following all felt earthquakes [6, 35]. ShakeMaps are available within minutes of an event occurring, and use data recorded at all the continuous real-time strong motion stations. Once the dial-up stations have been added to the event files, this information is also added to the ShakeMap.

### ***15.4.4 Moment Magnitude Estimates***

Another automatic product available within minutes of an automatic earthquake location that is felt inside Switzerland is a Moment Tensor solution [5, 10] based on broadband time-domain waveform inversion, which provides the moment magnitude of the earthquake. High quality solutions are typically available for events with  $ML > 3.5$ . Strong motion data can be used in this solution, though this is not routine as events in Switzerland are typically too small to generate long period energy (10–40 s) above the strong motion sensor noise level.

A second estimate of the moment magnitude, based on the spectral fitting of large numbers of records [11] is also routinely estimated for all events. This method produces good quality solutions for all magnitudes recorded by the Seismic Network. Strong motion data is routinely used in these solutions.

### ***15.4.5 Ground Motion Prediction Equations***

Numerous researchers have analysed the high quality waveform and event catalogue datasets made available by the SED [3, 4, 6, 12]. Both the dial-up and continuous strong motion data contribute to the compiled datasets, and are particular important components as a large proportion of the high amplitude records measured under 5 km epicentral distance are recorded on accelerometers. Site investigations at seismic stations in Switzerland are essential to reduce uncertainties in attenuation models and microzonation studies, and therefore to improve seismic hazard products. Such studies were performed in two projects. The first project concerned sites in the Basel area for a microzonation study, in densely populated urban environment ([18, 26]; Havenith et al., 2007). During the second project [15, 30], mostly sites of permanent seismic stations on rock were investigated, often in mountain areas and therefore on rough topography. The products from site characterization are stored in dedicated database and will shortly be made available to the seismological community.

### ***15.4.6 Site Effects***

The SED operates strong motion stations on both hard rock for seismological monitoring, as well as on soft and very soft soils in complex geological configurations and at urban locations, with the aim of better understanding site effects and the ground motions that the populations are subjected to. In the past recorded ground motions were used to validate results from numerical simulations used for microzonation studies, covering among others the region of Basel [18, 19] and the Valais [17] with detailed studies in the Sion [32] and the Visp regions [13]. The microzonation for the cantons Basel Stadt and Basel Landschaft has been recently implemented and is replacing the code spectra in the Swiss building code SIA261 ([19]; <http://www.geo.bl.ch/> and <http://www.geo.bs.ch/erdbebenmikrozonierung/>).

New permanent strong motion stations were placed in areas of observed damage during past earthquakes, e.g. the above regions with microzonation studies and Augusta Raurica [14, 17].

### ***15.4.7 Monitoring of Geothermal Exploration***

Fluid injections for geothermal energy production in Basel have triggered a series of earthquakes with magnitudes up to  $ML = 3.4$  in December 2006, resulting in a large number of buildings with small damage and sizeable reimbursement claims which ultimately led to the halting of the project. The SED has operated a number of temporary strong-motion instruments in addition to the permanent network around Basel, resulting in a high-quality and high-density seismic record of these small events. This allowed a detailed analysis of the induced earthquake series and the related impact in the Basel region [27, 30]. The monitoring of geothermal exploration since then has been widely implemented at sites of geothermal exploration in Switzerland (e.g. Brigerbad in the Valais, Triemli Zürich) [20].

### ***15.4.8 Early Warning***

The SED participates in early warning efforts in California, and methods developed in that region are being applied within Switzerland [6, 7, 8]. Densely spaced stations providing high quality waveform data with minimal latency are critical for any system that attempts to determine earthquake locations and magnitude estimates as rapidly as possible. The large number and quality of strong motion stations currently available, and the planned densification, will make strong motion a core component of an Early Warning System for Switzerland.

## **15.5 Conclusions**

The strong motion network in Switzerland is one of the densest not only in Europe has been in operation but also the world. A dial-up, low dynamic range network of 70 stations has been operation for nearly 20 years, and is in the process of being replaced by a large number of seismic observation quality strong motion instrumentation providing continuous real-time data with over 24 bit dynamic range, and frequency resolution from 200 Hz to DC. Currently, about 40 of these stations are operated by the SED, and we plan to install 30 more in the next 3 years, with an expectation to continue the expansion to a final total of 100 new stations.

The Swiss Seismological Service is the sole official source of earthquake information in Switzerland, and the SED Seismic Network group operates both the national strong motion and broadband networks. In practice, there is no separation in acquisition, processing and archival of the continuous real-time strong motion and broadband/short period data. The mature tools and software standard in the

seismic network community can thus be applied to our strong motion datasets: these include monitoring of station uptime and data quality, rapid earthquake detection, location and source estimation, real-time data exchange, permanent archival and event extraction.

**Acknowledgments** The regional upgrades of the strong motion network during 2003–2009 were supported by the Cantons Basel Stadt, Basel Landschaft, Valais and Graubünden through different Interreg III projects. The upgrade of the Swiss national strong motion network is supported by the Federal Office for the Environment (FOEN/BAFU) Federal Roads Office (FEDRO/ASTRA), Swiss Federal Nuclear Safety Inspectorate (ENSI), Swiss Federal Railways (SBB), Vereinigung Kantonaler Feuerversicherungen (VKF), and ETH Zürich. CCES project COGEAR supports the installation of a dense seismic network in the region of Visp and Matter valley in the Valais. The network maps were created by Sabine Wöhlbier.

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