Lessons from the 2012 ML=4.2 earthquake in Zug
Lehren aus dem 2012 ML=4.2 Erdbeben in Zug

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Introduction

The magnitude 4.2 earthquake that occurred on February 11 at 11.45 pm local time (10.45 pm UTC) between lakes of Zug and Ägeri, was the strongest earthquake to occur in Switzerland since the September 2005 magnitude 4.9 earthquake in Vallorcine (near Martigny). Last events of magnitudes 4 and above occurred in January 2009 (near Wildhaus, Toggenburg) and in May 2009 (near Steinen, Südschwarzwald, Germany). On a long-term average, there are one or two events of magnitude 4 in Switzerland per year, but there have been fewer than average in the last couple of years.
On a global scale, the earthquake hazard in Switzerland is moderate. However, there is on average one magnitude 6 event every 100 years in Switzerland. Such an event can cause severe damage to buildings that were not built according to modern earthquake safety standards in a radius of several tenths of kilometers. The 1356 Basel earthquake had a magnitude estimated at 6.6 and was the largest historical earthquake in Europe north of the Alps. According to the last studies, the recurrence period of such an event is between 1500 and 2000 years.
The largest event in a 30 km radius around Zug was an earthquake with estimated magnitude Mw=4.5 occurring in Thalwil in 1674. 6 earthquakes of magnitude 4 to 4.5 occurred in this region in 500 years, indicating that this part of Switzerland was less active than others like the Valais or the Basel region. Active faults in Switzerland are poorly known, *a fortiori* in regions with lower seismicity. Recording the earthquake activity is the only mean to fill this gap in the hazard estimation.
This paper summarizes what could be learned on the source of this event and on the ground shaking that it caused. For these purposes, the two basic data sources used are the recordings at seismic stations and answers of the general public to the online questionnaire of SED. This paper is based on an internal SED report (SED, 2012).

1. Earthquake Source

The real-time network of SED allowed to preliminary locate the event within the two first minutes and alerted the authorities, the scientists and the media. The event was automatically added on the SED website http://seismo.ethz.ch. A duty seismologist then refined manually the picking (Fig. 1). The local magnitude ML of SED and others agencies spread between 3.7 and 4.3. Alternative magnitude estimates using the moment magnitude Mw provided values of 3.7-3.8. The spread observed here is expected due to the various methods being used, different origin locations, and the heterogeneous station sets available.

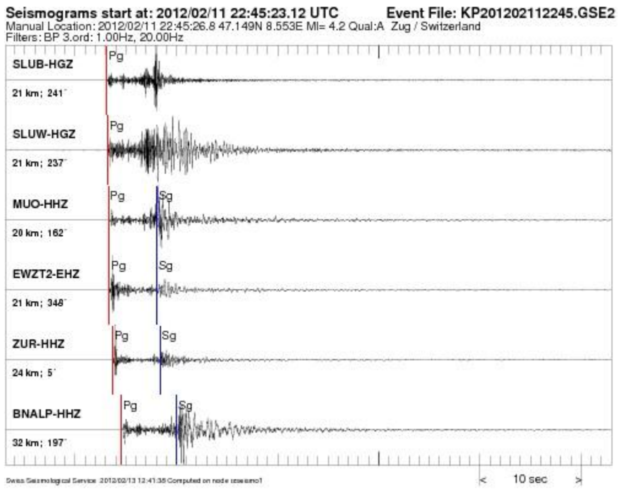


Figure 1: Some recordings used to locate the earthquake hypocenter. The red mark depicts the onset of the P-waves, the blue mark depicts the onset of the S-waves.

The hypocenter (the earthquake's origin within the Earth) was found to lie at an approximate depth of 30 km, slightly above the "Moho", which marks the transition between the Earth's crust and the mantle (Fig. 2). The automatic moment tensor solution indicates the event is predominantly strike-slip with a normal component, which cannot be directly interpreted in terms of tectonic considering the poor knowledge of the region. Like most seismic activity in Switzerland, this earthquake is an expression of the tectonic stresses across the Alpine region. These stresses result from the collision between the European and the African continental plates, which has led to the formation of the Alps.

In the 2 weeks following the mainshock, 3 aftershocks have also been recorded with similar locations and depths. A ML 1.1 occurred at 18:15UTC at 28 km depth on 14 Feb, followed by a ML 1.6 at 09:04 at 29 km depth on 18 Feb. Both were too small to be felt. A larger aftershock, ML 3.5, occurred at 00:32 at 32 km depth and was widely felt across Kantons of Zug, Lucerne and Zurich.

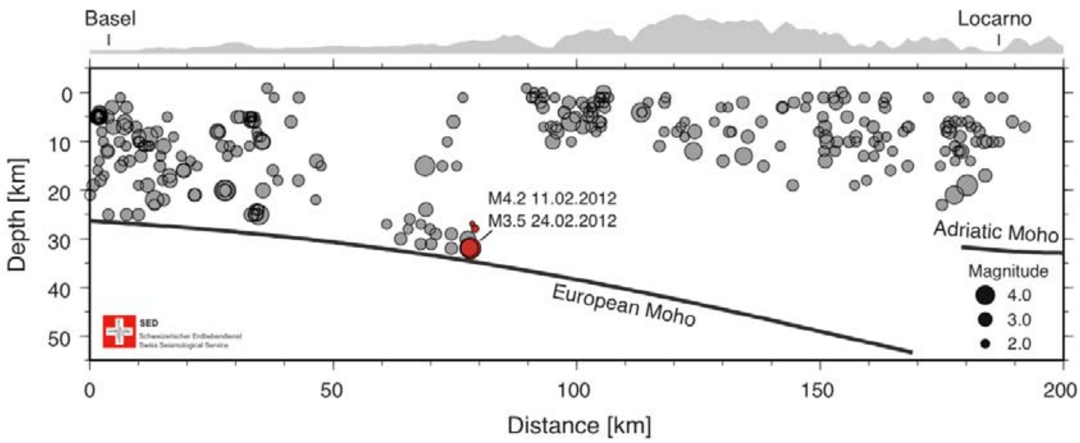


Figure 2: Depth cross-section from Basel to Locarno showing seismicity from 1985-2012 (grey circles) as recorded by the SED. The M4.2 mainshock of February 11, 2012, and its three aftershocks are marked by red circles. Only earthquakes within a swath of ±50 km of the profile and with well constrained focal depths are shown.

2. Severity of the ground motion

2.1 Macroseismic data and public response

The earthquake was clearly felt all over the German-speaking parts of Switzerland, as well as in the Wallis and the Tessin, but strongly touched the eastern and central midland, as far as the eastern extensions of the Jura, the Basel area and Lake Constance. As expected, the perceived shaking was strongest near the epicenter (the point on the Earth's surface directly above the hypocenter). Earthquakes of this magnitude may cause damage at short distances but in this case, the ground motion was largely attenuated before it struck the surface due to the large depth of the hypocenter.

On the European Macroseismic Scale (EMS-98), which quantifies the ground motion at the surface from observed effects, the event was classified between IV and V in the epicentral region (Fig. 3). The intensity V corresponds to minor sporadic damage to buildings (e.g. plaster cracks), whereas no damage occurs for intensity IV. 3500 questionnaires have been filled by the general public spontaneously after the earthquake on the SED website. On these 3500 questionnaires, 100 contained reports on hair-like fissures. Media also documented cracks in walls. However, the ground motion most likely made visible existing cracks that were covered with plaster or paint prior to the earthquake. Actual damage to civil engineering structures is excluded for this ground motion amplitude as shown in the next section.

Many people reported a loud "bang", similar to an explosion, at the beginning or even slightly before the ground shaking, from unusual distances up to 40 km. Such a sound may be produced when seismic waves hit the Earth's surface, inducing sonic waves. "Bang"-like sounds can be produced from higher frequency seismic waves. The generation of such noise depends on local conditions and can vary strongly even over short distances.

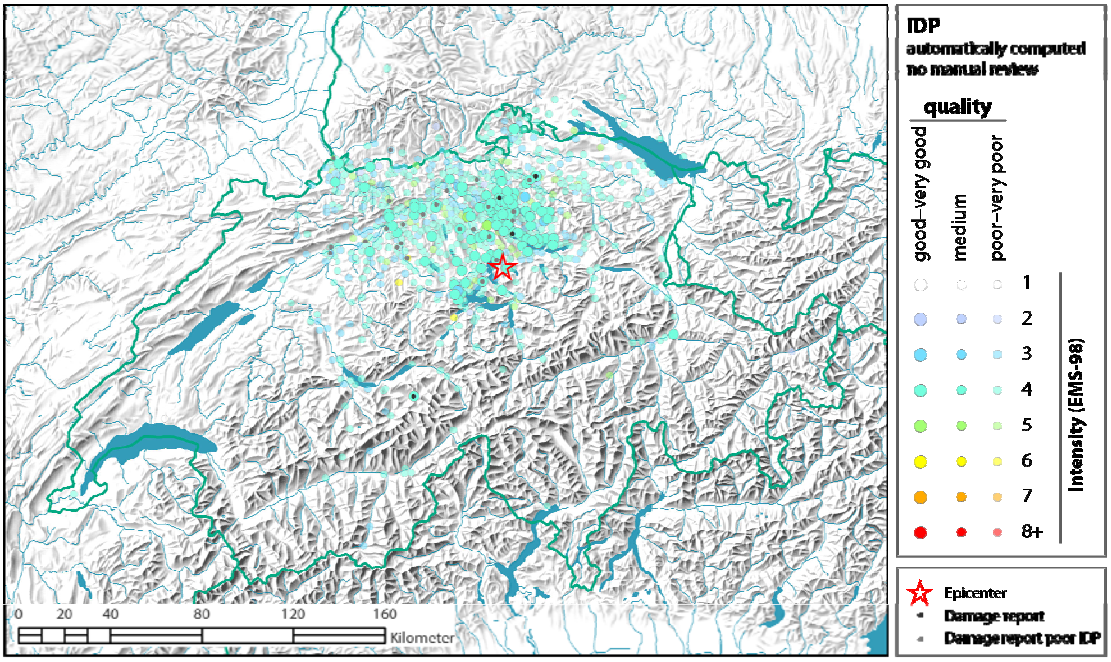


Figure 3: automatically computed macroseismic intensity, based on data of the online-questionnaire (not manually revised yet).

Within seconds of the event's origin time, the SED webpages were not reachable due to the overload of connections. The pages were loading at a normal rate again only 45 minutes later. Measures are ongoing to increase the capacity of the servers for future events.

2.2 Strong motion recordings

SED is operating nearly 100 real-time stations, broadband and strong motion, a great majority of which recorded well the event. Additional 5 dial-up strong motion stations (on 70), in Sarnen, Linthal, Basel, Schaffhausen and Brig, triggered for the main shock. The peak ground accelerations (PGA) of all stations are displayed versus distance in Figure 4. Recording sites are qualitatively segregated into rock, stiff sediments and soft sediments. This classification allows to explain part of the ground motion variability, but as usually observed, the ground motion is extremely variable within short distances due to source, path and site effects. The maximum acceleration occurred at SLUB (Luzern Bramberg) and SARG (Sarnen Gewerbe) at 21 km and 36 km from the epicenter, respectively, with ca. 14 cm/s^2. The largest peak velocity and peak displacement were recorded in SLUW (Luzern Werkhofstrasse), the closest station to the epicenter at 21 km, with values of 0.25 cm/s and 0.15 cm, respectively.

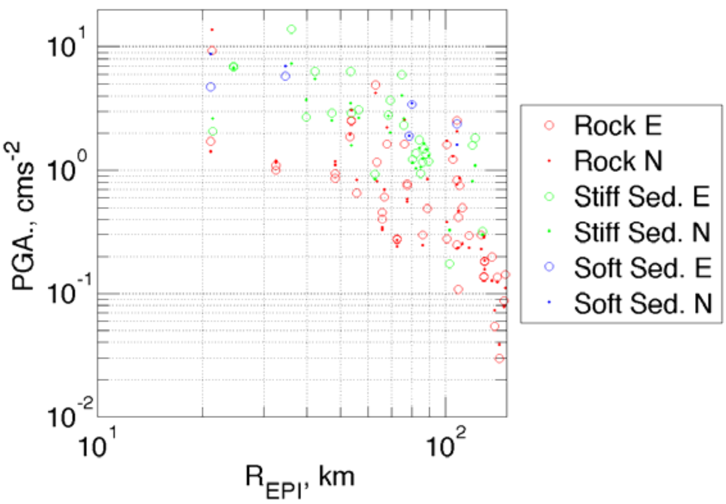
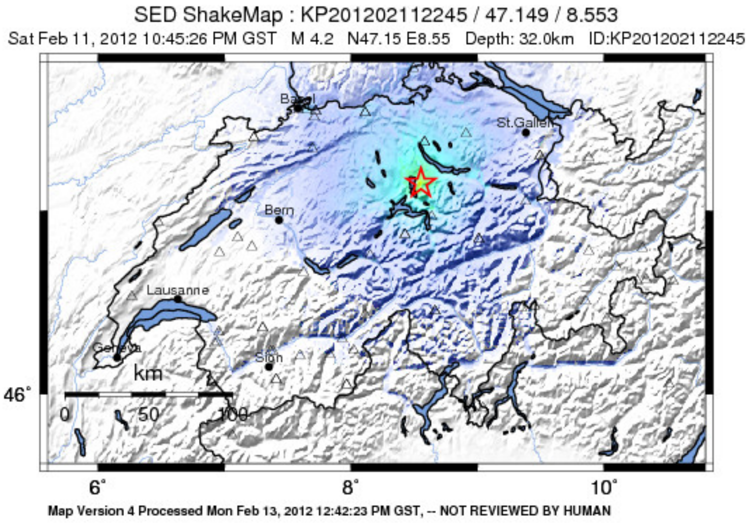


Figure 4: Attenuation of horizontal PGA values as a function of epicentral distance (East and North components).

The SED produces ShakeMaps (Wald et al., 1999) that combine both the observed ground motions recorded at the Seismic Network as well as the predicted ground motions knowing the event origin and magnitude, the expected ground motion attenuation and local site amplifications. It was available on-line within 6 minutes. The ShakeMap in Figure 5 is consistent with the widespread reports of the event being felt across the N and NE of the country, extending southwards to the Ticino.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 5: SED ShakeMap for the 2012 Feb 11 23:45:26 ML 4.2 Zug Earthquake.

3. Focus on Lucerne

In Lucerne, at ca. 21 km from the epicenter, 2 strong-motion stations have recently been installed as part of the renewal of the strong-motion network. These very high-quality stations are located on a hard rock hilly outcrop (SLUB, Bramberg) and in the center of the city, on soft sediments in the deeper part of the Lucerne basin (SLUW, Werkhofstrasse). The striking differences in the recorded ground motion reflect the very different site amplifications on these sites separated only by less than 1500m (Fig. 6). The recordings in SLUB show a short impulsive signal with a PGA of 14 cm/s^2, whereas the recordings in SLUW have a longer duration with larger low-frequency waves, but with a lower PGA of ca. 9 cm/s^2.

The standard spectral ratios SLUW over SLUB (Fig. 7) show very large amplifications at SLUW in both horizontal directions between 1 and 5 Hz, up to a factor 15 at 1 Hz. The amplification factor obtained using the ML 3.5 aftershock recording is similar. In Figure 7, the fundamental resonance frequency f0 obtained from ambient vibrations (AV) is displayed as well. The waves with short wavelengths compared to the Lucerne basin size are trapped in this basin, increasing the ground motion amplitude above its resonance frequency, which is commonly called a site effect. The 1D layering alone cannot explain so high amplifications, actually due to the 3D basin geometry.

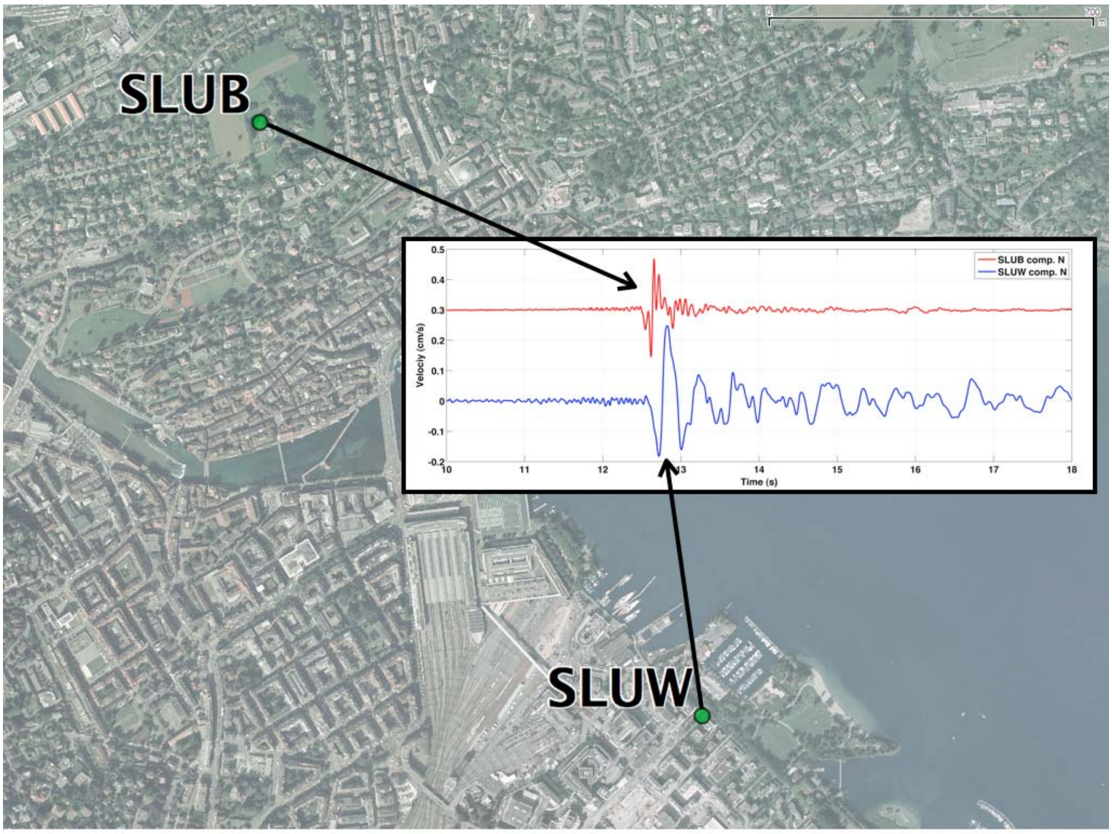


Figure 6: Waveforms in Lucerne (N component) integrated into velocities.

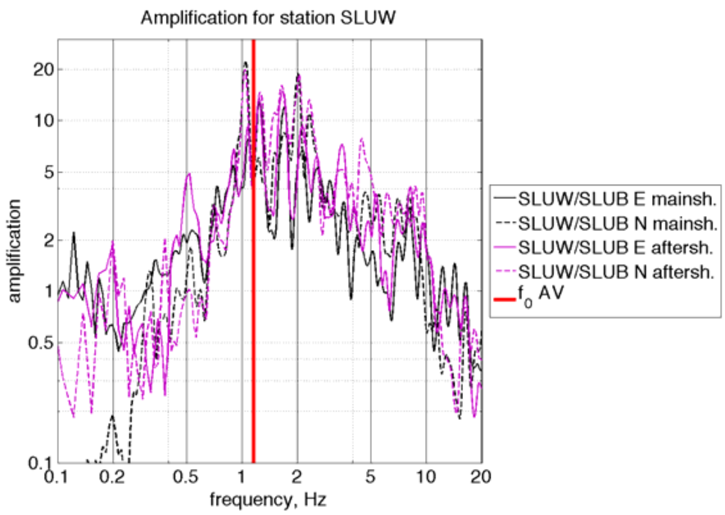


Figure 7: Amplification at SLUW.

The 5% damped response spectra of the mainshock are displayed in Figure 8 together with the design code SIA261 in zone 1 corresponding to the Lucerne area. It shows that the reached amplitudes are 5 to 10 times lower than the design ground motion. At low periods (high frequencies), SLUB recordings are above SLUW recordings (higher PGA), whereas above 0.2 s (below 5 Hz), SLUW recordings are up to 4 times larger in displacement and acceleration than in SLUB. According to this figure, the motion at the top of buildings did not exceed 0.5 mm in the basin, which is too low to generate damage, even slight.

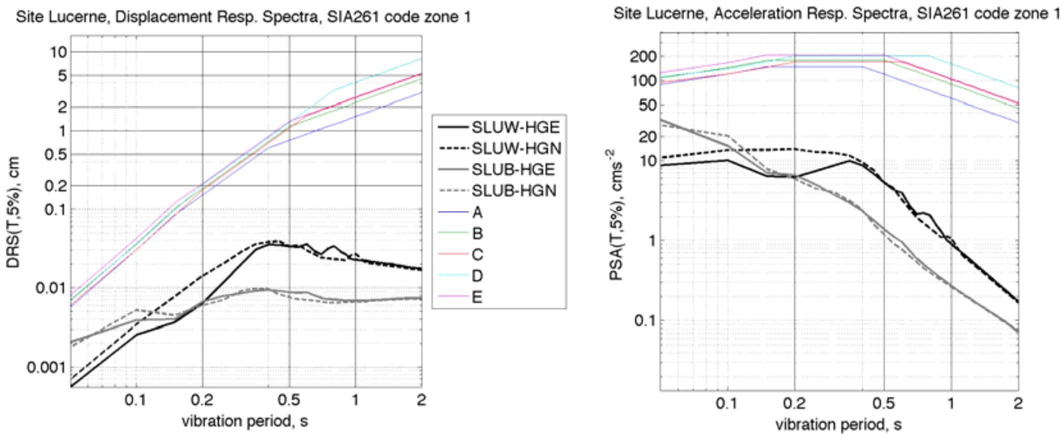


Figure 8: Response spectra (left: acceleration; right: displacement) in Lucerne compared to SIA261 (zone 1) design code for the A, B, C, D and E subsoil classes.

Conclusions

Earthquakes like the Ml=4.2 Zug event occur statistically in Switzerland every year, although last 20 years were particularly quiet. SED developed in the last years monitoring tools and real-time products that allow a quick assessment of causes and effects of earthquakes in Switzerland for dissemination to the authorities, the scientific community and the general public. Such an earthquake allows to test these systems and procedures and eventually correct them for better response to a possibly large event.

Moreover, this earthquake provided data to study strong ground motions in Switzerland since it was well recorded by the greatest part of the real-time network operated by SED. Recordings in Lucerne, at 21 km from the epicenter, showed particularly large amplifications up to a factor of 10 (factor of 4 in response spectrum) in the city center compared to a rock site nearby.

Applying seismic building codes is the better way of decreasing seismic risk but codes are relying on the hazard estimation that has to be accurate enough. Microzonation, which consists in refining the hazard estimation, including the effects of surface geology, is therefore critical for Swiss cities. This earthquake also showed how important are the validation and the updating of microzonation studies using actual earthquake recordings by installing permanent or temporary strong motion stations in these cities.

References

SED, “SED significant earthquake report: 2012 Feb 11 23:45:26 ML 4.2 Zug Earthquake”, Swiss Seismological Service, 2012.

Wald D. J., Quitoriano V., Heaton T. H., Kanamori H., Scrivner C. W., and Worden C. B., TriNet “ShakeMaps”: Rapid Generation of Instrumental Ground Motion and Intensity Maps for Earthquakes in Southern California, *Earthquake Spectra*, **15**, 537-556, 1999.