Installation of a very broad band borehole seismic station in Ferrara (Emilia)

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a) Introduction

The Istituto Nazionale di Geofisica e Vulcanologia (INGV) is the Italian agency devoted to monitor in real time the seismicity on the Italian territory. The seismicity in Italy is of course variable in time and space, being also very much dependant on local noise conditions. Specifically, monitoring seismicity in an alluvial basin like the Po one is a challenge, due to consistent site effects induced by soft alluvial deposits and bad coupling with the deep bedrock (Steidl et al., 1996). This problem was tackled by INGV first with the Cavola experiment (Bordoni et al., 2007), where a landslide was seismically characterized using a seismic array and also down-hole logging of P- and S-wave travel times at a borehole drilled within the array; later, with an ad hoc project in 2000-2001, with the first installation of a broad band seismic station nearby Ferrara in a borehole of 135 meters depth. Comparison of recordings with a surface seismic station indicated a noise reduction of 2 decades in power spectral density at frequencies larger than 1.0 Hz (Cocco et al., 2001). The instrumentation in Ferrara has been working for several months but after that the seismic station was discontinued due to lack of maintenance manpower.

The Centro di Ricerche Sismologiche (CRS, Seismological Research Center) of the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS, Italian National Institute for Oceanography and Experimental Geophysics) in Udine (Italy) after the strong earthquake of magnitude M=6.4 occurred in 1976 in the Italian Friuli-Venezia Giulia region, started to operate the Northeastern Italy (NI) Seismic Network: it currently consists of 15 very sensitive broad band and 21 simpler short period seismic stations, all telemetered to and acquired in real time at the OGS-CRS data center in Udine (Fig. 1).

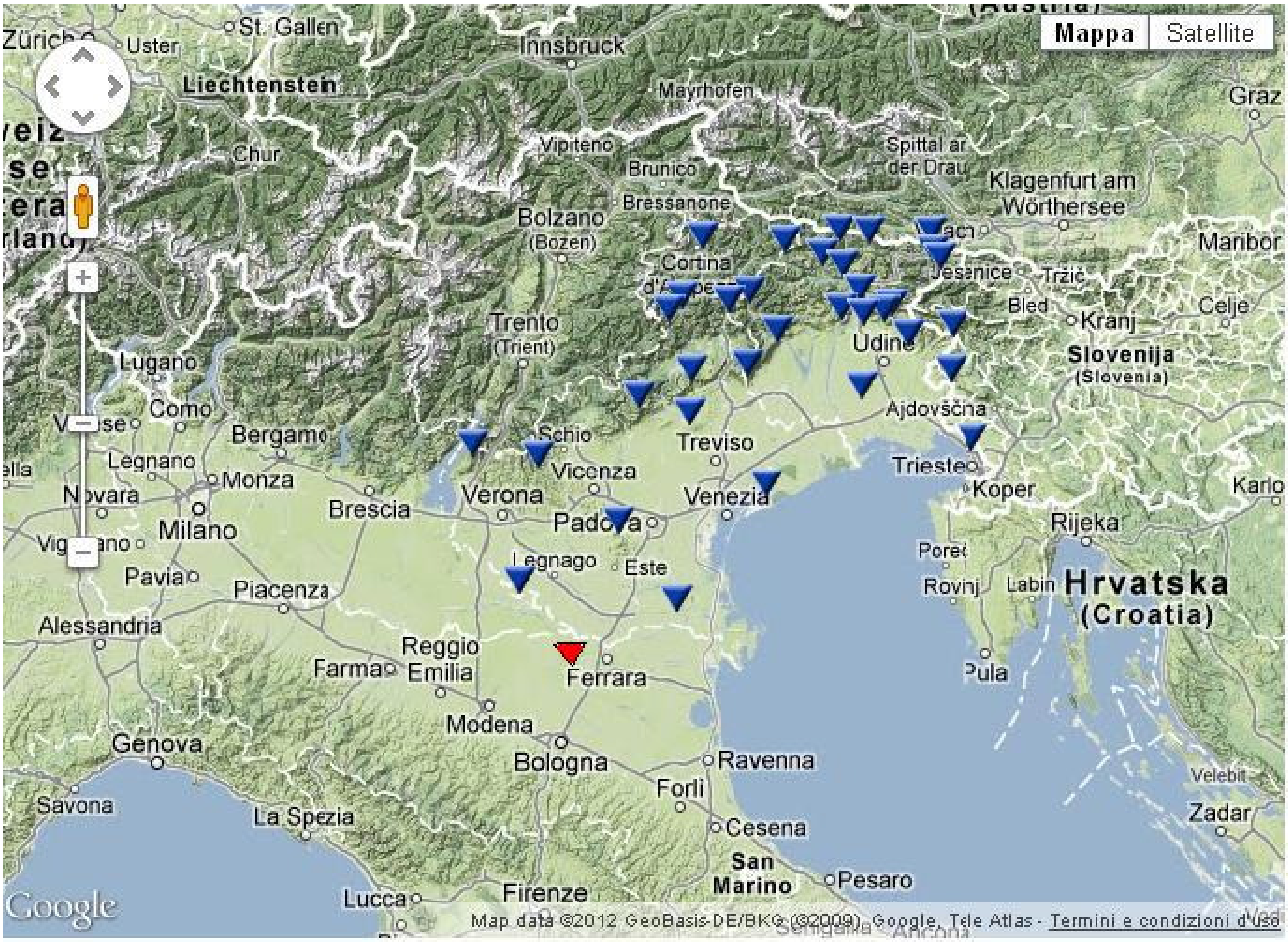

Figure 1 – The North-eastern Italy Seismic Network (NI) run by OGS with the Ferrara borehole site in red

Real time data exchange agreements in place with other Italian, Slovenian, Austrian and Swiss seismological institutes lead to a total number of about 100 seismic stations acquired in real time, which makes the OGS the reference institute for seismic monitoring of Northeastern Italy. Since 2002 OGS-CRS is using the Antelope software suite on several workstations plus a SUN cluster as the main tool for collecting, analyzing, archiving and exchanging seismic data, initially in the framework of the EU Interreg IIIA project “Trans-national seismological networks in the South-Eastern Alps”. SeisComP is also used as a real time data exchange server tool (Bragato et al., 2011). Among the various Italian institution with which OGS is cooperating for real time monitoring of local seismicity there is the Regione Veneto (Barnaba et al., 2012). The Southern part of the Veneto Region stands on the Po alluvial basin: earthquake localization and characterization is here again affected in this area by the presence of soft alluvial deposits. OGS ha already experience in running a local seismic network in difficult noise conditions making use of borehole installations (Priolo et al., 2012) in the case of the monitoring of a local storage site for the Italian national electricity company ENEL. Following the M_L=5.9 earthquake that struck the Emilia region around Ferrara in Northern Italy on May 20, 2012 at 02:03:53 UTC, a cooperation of INGV, OGS, the Comune di Ferrara and the University of Ferrara lead to the reinstallation of the very broad band borehole seismic station in Ferrara. The aim of the OGS intervention was on one hand to extend its real time seismic monitoring capabilities toward South-East (Fig. 1), including Ferrara and its surroundings, and on the other hand to evaluate the seismic response at the site.
As concerns the superficial geology of the area where the borehole seismic station has been installed, the outcropping materials are represented by alluvial deposits of different environments, like channel and proximal levee, inter-fluvial, meander and swamps deposits. As a consequence,

the outcropping deposits are everywhere Holocene in age substantially loose or poorly compacted in the first meters-decameters and granulometrically could vary from clay to coarse sand.

Two preliminary reports prepared by the Italian Department of Civil Defense (Dipartimento Nazionale di Protezione Civile) in collaboration with other institutions describe the data recorded by the national accelerometric network and complemented by additional data recorded by a number of temporary stations (Dolce et al., 2012a; Dolce et al., 2012b). These reports bear witness of strong ground motion values with an acceleration peak of about 0.9 g in the vertical component recorded during the M_L=5.8 earthquake of May 29, 2012 by the Mirandola station, located at about 2 km from the epicentre. The analysis of the seismic noise recorded at some stations shows a quite pronounced peak of the horizontal-to-vertical spectral ratio (H/V) in the frequency range of 0.6 – 0.9 Hz common to all stations. Finally, strong evidence of liquefaction phenomena are reported at several sites (e.g.: S. Carlo, S. Agostino and Mirabello), most of which have been attributed to the occurrence of saturated sandy layer(s) at shallow depth deposited along an abandoned reach of the Reno River (Papathanassiou et al., 2012).

Details of the station configuration and installation will be outlined, with first results.

b) Main

The instrumentation installed in Ferrara is a Guralp borehole very broad band seismometer CMG-3T with a flat response between 360 seconds and 50 Hz (Guralp Systems Ltd., 2006), coupled with an accelerometer Guralp CMG-5T (Fig. 2). The digitizer is a Guralp DM24 borehole version, with 24 bit resolution and 6 channels. Data channels are sampled at 100sps for both the seismometer and the accelerometer, and at 1sps for the seismometers and the state of health channels, including timing, masses positions, voltage and temperature. In Figure 2 both the sensor system made by the very broad band seismometer coupled with the accelerometer and the digitizer are illustrated, together with the control box necessary to extract/extend the holelock system to fix the all system down in the borehole.

Figure 2 – Guralp CMG-3T/5T borehole sensor with DM24 digitizer and control box

The installation of the sensor in the borehole required some caution. First we connected the sensor with the digitizer with its data cable and its locking system. Then we connected to the digitizer 160 meters of data cable and the same length of steel cable to hold the all system. We slowly lowered the all system in the borehole being careful to tight together the two cables (the data and the steel ones) every 10 meters or so, to avoid obstruction of the hole. Once we reached the bottom of the borehole, we raised the system of some meters. We then fixed the sensor with its holelock system and lowered the digitizer on top of it until the digitizer own locking system held. At this point we tightened the all system at the surface.

At the surface we installed a rack with a Guralp EAM data acquisition system running Scream software and a SeedLink server. The CMG-EAM (Embedded Acquisition Module) is a versatile module intended to integrate one or more seismic sensors with various communications systems. It can also act as a stand-alone data recorder or as a communications hub in larger networks. The unit is a Linux-based devices but no Linux knowledge is required to run it, thank to its web interface. The use of Linux provides a high degree of flexibility: additional functionality can often be added on request. The system is connected to the internet via a GPRS modem accessible from internet. the remote operation and control software is accessible via internet with a normal web browser. All the system features are coded with colours, with a green colour indicating normal functioning. The web interface shows also GPS coordinates of the station (44.90°N and 11.54°E).

Data is recorder locally in the Guralp EAM system in files separated by component and one hour long in time. The systems has an internal hard disk of about 80 GigaByte that is powered up only when used: this limits power consumption for better reliability. The data format chosen is the standard MiniSEED, which is a station subset of the more comprehensive Standard for the Exchange of Earthquake Data (SEED) widely internationally used format (Ahern et al., 2007).

The borehole very broad seismic station installed in Ferrara was able to correctly record the event of September 14 2009 at 02:47 GMT with magnitude M_L=3.2 occurred at a distance of 20 km as indicated in Fig. 3.

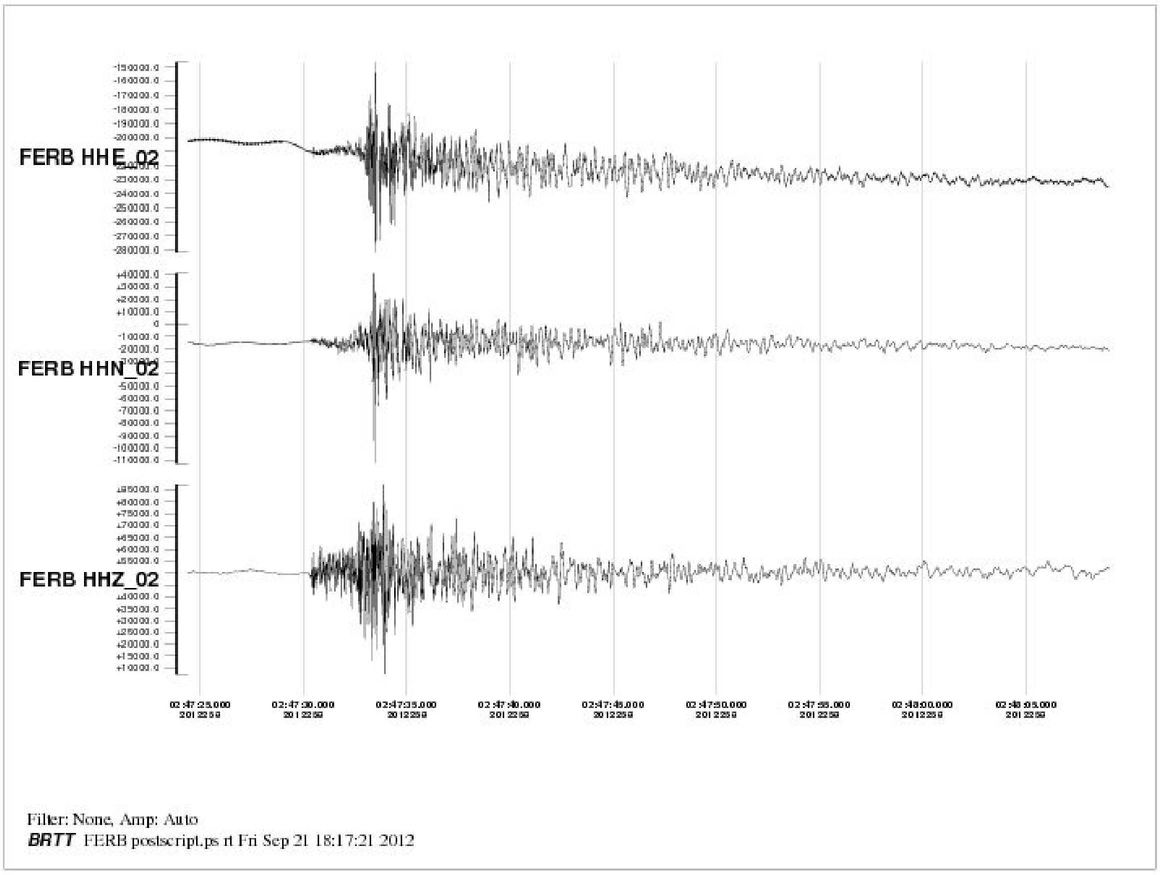

Figure 3 – M_L=3.2 event recorded by FERB VBB borehole station

The orientation of the borehole sensor will require correlation with the recordings of a teleseismic event by a surface installation at the same site managed by Ferrara University.
The very broad band borehole seismic station of Ferrara has been already integrated in the main Antelope seismic data real time acquisition system at OGS-CRS premises in Udine, and it will soon be integrated also in the Italian National Seismic Network run by INGV in Rome. The data connection is realized through the GPRS data link by making use of the standard Antelope software module "slink2orb". This module act as a client grabbing data from the remote SeedLink server at the Ferrara borehole seismic station, feeding the data into the main Antelope server in Udine. Channel renaming was required to follow international SEED conventions (Ahern et al., 2007). Data will be forward from OGS premises in Udine to INGV premises in Rome and Fearrara University premises in Ferrara through a standard SeedLink connection. All institutions involved (OGS, INGV and Ferrara University) are in fact already making use of the SeisComP software suite to collect, exchange, store and analyze seismic data in real time. The seismological software SeisComP has evolved within the last approximately 10 years from pure acquisition modules to a fully featured real-time earthquake monitoring software. The now very popular SeedLink protocol for seismic data transmission has been the core of SeisComP from the very beginning. Later additions included simple, purely automatic event detection, location and magnitude determination capabilities (http://www.seiscomp3.org/wiki/about).

Detailed seismic noise and propagation studies will be conducted at the Ferrara borehole site. It is well known that although the magnitude and distance are first-order factors that control ground motion, site condition can generate significant changes in earthquake effects on buildings. Therefore, site characterization is one of the most important goals of earthquake engineering and it is an important ingredient in accurate empirical ground-motion prediction relations. However, a good quantification and understanding of the site response starts from the noise knowledge of each site. It has long been known that the reduction, quantification and understanding of seismic background noise are the first step to provide high quality data. The background noise is a limiting factor since it can mask seismic signal, especially in the low-frequency band. The importance of noise level reduction on seismic data is strongly linked to quantify the detection level of the network, that reflects directly on the completeness magnitude of an area and indirectly on the calibration of attenuation relations through regression analysis, which may be biased by non-triggering stations (McLaughlin, 1991; Bragato and Slejko, 2005).
The noise affecting the seismic signals that reducing the signal-to-noise ratio is interpreted like the sum of electronic noise, atmospheric fluctuations (pressure, temperature and humidity) and seismic noise. For what the installation of the very broad band borehole seismic station in Ferrara is concerned, our attention will focus only on the seismic noise, while the electronic noise, mainly produced by seismic sensors self-noise, datalogger self-noise or near-field electric cabling, will not investigated in detail.
Seismic noise has been extensively studied in the past. A detail bibliography is available in Bonnefoy-Claudet et al. (2006). The conclusions of these observations at different sites all over the world are consistent with each other and may be summarized as follows: i) at long periods (below 0.3 to 0.5 Hz), seismic noise is caused by ocean waves long distances away; ii) at intermediate periods (between 0.3-0.5 Hz and 1 Hz), it is mainly generated by both close coastal sea waves and wind; iii) beyond 1 Hz, it is linked to human activity, and therefore reflect the human cycle.
It has long been known that each soil type responds differently when subjected to a ground motion from earthquakes. Usually, the younger, softer soils amplify ground motion relative to older, more competent soils of bedrock. One of the goals of engineering seismology has been to try to quantitatively measure this amplification of ground motion throughout metropolitan regions in earthquake-prone areas. These measurements, like the ones that will be conducted at the Ferrara borehole site, can then be used to help distinguish areas where the seismic hazard is greatest due to amplification from the surface geology and subsurface structure. The varied damage patterns seen over small distances in the wake of large earthquakes is easily understood when looking at the variations over small distances in recorded ground motions.
A common factor in many of the methods for estimating amplification of ground motion at a particular site due to its near-surface geology is to use a nearby bedrock site – like our borehole – as the reference motion. The critical assumption in these methods is that the surface-rock-site record (reference) is equivalent to the input motion at the base of the soil layers. Given that the imput motion below the soil layers - unless making using of a borehole installation like the one in Ferrara – is not usually know, for practical reasons, seismologist will use the nearby rock site and make this assumptions. In an attempt to understand the variability in nearby sites, we will compare data from a series of surface installation with the one of this borehole installation.
The results will be presented by first showing the empirical estimation of site response in Ferrara. This borehole sensor located below the soil column in competent granitic rock will be used as the denominator in Fourier spectral ratio estimates of amplification. We will also compare this empirical estimate with theoretical calculations of the site response in Ferrara, which are derived from available geotechnical data. This will indicate the usefulness of the borehole rock motion as a reference site

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