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Recent scientific results from the instrumented sites and structures led by the French Accelerometric Network: examples of the Grenoble and Belleplaine vertical arrays.

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ABSTRACT

France is a country of moderate seismicity but, due to the density of urbanized and industrial areas the seismic risk is significant. Furthermore, recent developments in numerical and semi-empirical methods request a good knowledge of several parameters. The mission of the French accelerometric network program (RAP, Réseau Accelerometrique Permanent) is to expand and modernise significantly the acquisition and application of French accelerometric data (both strong and weak motion) in order to improve earthquake related research and public safety from earthquakes. This network includes specific sub-networks for site effects analysis, building response and earthquake geotechnical engineering activities. This paper presents the networks, the tools for sharing data (open-access data) and specific sub-networks activities, with a special focus on the deep and shallow vertical geotechnical arrays.

Introduction

The main objective of the RAP (Péquegnat et al., 2008) is to record, process, analyse, provide, and disseminate information on accelerometric waveforms so as to provide high-quality data and information quickly whenever needed by the scientific community, local and national authorities, or the general public. Launched in 1995, a scientific consortium was created in 2000 to form a network of all the scientific and operational entities involved in understanding and monitoring seismic hazard and vulnerability in France. The French Accelerometric Network consortium (RAP) includes 10 French partners under the supervision of two administrative agencies. The main role of the RAP consortium and its scientific board is to decide and plan an instrumentation policy consistent with the scientific aims of the project and for future scientific purposes.

Since 1995, around 160 stations have been set up in seismic areas of France (Fig. 1), located in the most active regions in France (Alps, Pyrenees and Central mountains, Western regions, French West Indies). The stations are operated by academic and public agencies, all stations are

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equipped with a 24-bytes acquisition system and force-balance accelerometer, designed for resolution between weak to strong motion produced by typical French earthquakes. The network has evolved towards real-time and continuous near-real time distribution and archiving. This effort also includes specific research objectives (e.g., site effects, building monitoring, vertical geotechnical borehole arrays, etc.)..

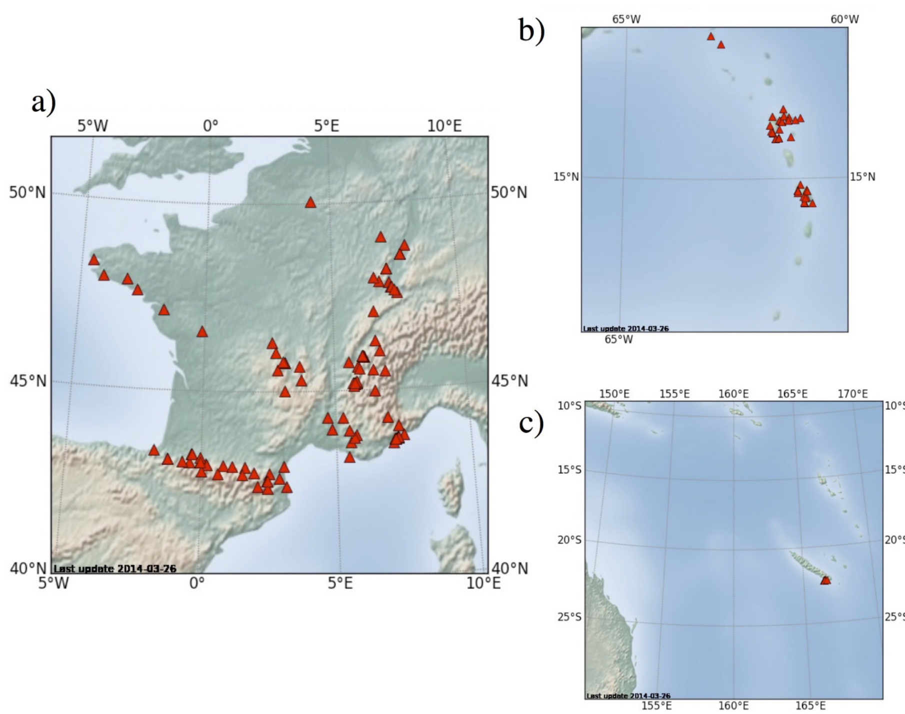

Figure 1. Localisation of the accelerometric station in (a) France mainland, (b) French West Indies and (c) New Caledonian Island

The main objective of this paper is to present the RAP network activities and its specific sub-networks devoted to specific research activities, the data available, the mechanisms provided to end-users for sharing the data and the specific description of Earthquake Geotechnical Engineering vertical arrays.

Description of the network

Most of the RAP's stations are installed in free-field rock or sediment sites and data integrate the national seismological networks installed for the seismic activity monitoring at the France territory scale. However, RAP implements site-specific operations for which specific sub-networks have been designed with particular aims. The importance of site effects observed in several cities triggered instrumental studies conducted by the RAP, in different sediment and tectonic contexts. For example, in Grenoble (northern French Alps), the deep Y-shaped alpine valley created during a major glacial period (Würmian, 25,000 years ago) produces strong 2D and/or 3D effects (Cornou et al., 2003) at low frequency (resonance frequency of the valley close to 0.3Hz). In Nice (south-eastern region), three types of sediments are observed: thin layers of fluvial sediments, thick formations of pudding stones, and rocky mountains made of marly limestone, producing amplification between 1-5Hz. Annecy in the Alps and Bagnères-de-Bigorres in the Pyrénées mountain ranges are two additional urban areas completing the RAP site effects sub-networks. For each site, several stations are recording earthquakes at sediment and rock sites that provided data for several scientific activities, such as computing 1D or 2D site amplifications, simulation of seismic strong motion using empirical Green functions, spatial variability of seismic ground motion in urban environment, etc. In addition, an active landslide in the Alps (Séchilienne Landslide) is also monitored by accelerometric stations located outside and inside the mass in motion for amplification analysis along a slope.

Another activity concerns the permanent monitoring of five buildings located in France and in the West French Indies (Martinique Island). The National Building Array Program (NBAP) started in 2004. Its aim is the seismic response analysis of typical French buildings for seismic vulnerability assessment. Buildings are :

- The Grenoble City Hall, a 44x13x52m (LxTxH) shear-wall reinforced concrete building, completed in 1967, founded on very soft soil (the Grenoble basin), has been monitoring since 2004 with three 3C accelerometers (EST) located in the corners at the top and the bottom of the structure; station name OGH1 to OGH6 (Michel et al., 2010; Mikael et al., 2013).
- The (CDST) building, a 50x18x8m shear-wall reinforced concrete building, founded on base-isolating (rubber bearing) systems in Martinique (French West Island), has been monitoring since 2005 with two 3C-accelerometers (EST) located in the upper and the lower parts of the base isolating system; station name CGLP and CGLR (Guéguen, 2012).
- The Ophite Tower building, a 24x19x50m shear-wall reinforced concrete structure, completed in 1972, founded on very stiff rock (Ophite rock), has been monitoring since 2008 using 24 mono-axial or 3C EST accelerometers distributed along the height of the building and temperature measurement; station name PY01 to PY10 (Mikael et al., 2010).
- The Nice Prefecture building, a 45x15x68m shear-wall reinforced concrete structure, completed in 1980, founded on soft sediment (Var river deposits), has been monitoring since since 2010 using 24 mono-axial or 3C EST accelerometers distributed along the height of the building and temperature measurement; station name NCAD.
- The Basse-Pointe School building, a 55x9x10m shear-wall reinforced concrete structure, completed in early 70's, founded on stiff sediment, has been monitoring since 2011 using 24 mono-axial or 3C EST accelerometers distributed along the L, T and H direction of the building, and temperature measurement; station name CGBP.

Finally, earthquake geotechnical engineering test sites are also part of the RAP activities. It concerns one deep (station name OGFO) and one shallow borehole (station name LIQF) drilled in the deep sedimentary basin of the Grenoble Valley and in the shallow soft sediment in Guadeloupe Island (French West Indies), respectively. Both sites have permanent vertical accelerometric array, based on shallow and deep episensors 3C-accelerometers located at GL0m, GL42m and GL565m (GL: ground level) for the Grenoble deep borehole and GL0m, GL15m and GL35m for the shallow borehole. The description of the geotechnical arrays is given in the last section.

Description of the data

RAP is the accelerometric component of the French Seismological and Geodetic Network (RESIF). All data are archived and freely distributed by the RAP's National Data Centre (RAP-NDC) for seismology, engineering seismology, and earthquake engineering purposes. This national data centre is hosted at the University of Grenoble-Alpes and integrated through the national data centre for seismological data (RESIF data centre: http://www.resif.fr). Data are referenced thanks to its Digital Object Identifier DOI 10.15778/RESIF.RA

All the data are freely available through web portal. The 125 sps data are collected by regional networks in charge of the maintenance and the supervision of stations located in their region and sent in near real-time directly to the RESIF-Data centre for a long-term archive where they are permanently saved. The data are in SEED format, the waveform being referred to as the miniSeed files and the network-station information is referred to as the metadata. SEED volume is done according to the international standard for exchanging data between digital seismological networks (FDSN: http://www.fdsn.org/), respecting the syntax and the format of the standards. This format can be read using rdseed software that are available at the IRIS-DMC website (http://ds.iris.edu/ds/nodes/dmc/). Rdseed allows to convert the data into SAC, AH, or CSS formats and it exists Matlab routines to convert SAC files to ASCII.

There are several ways to request RAP data depending on whether you are requesting them from continuous and long-term archives or from event-oriented services. To request data from the permanent archive, different ways can be used (after Volcke et al., AGU poster 2013):

- Getting realtime data streams: seedlink protocol at rtserve.resif.fr (port 18000);
- Getting continuous and triggered validated data and metadata: connect to our Webservices server at ws.resis.fr (port 80) (Webservice of the Federation of Digital Seismological Network, FDSN);
- Getting continuous, triggered validated data and metadata from the European data archive (EIDA): connect to our arclink server at eida.resif.fr (port 18001) or through the website of the European infrastructure for seismological data sharing http://www.orfeus-eu.org.

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Earthquake Geotechnical Engineering test sites

The Grenoble deep borehole (OGFO name)

To determine the geophysical characteristics of the sedimentary fill of the Isere valley in the Grenoble area, the Institute of Nuclear Protection and Safety (Institut de Radioprotection et de Sûreté Nucléaire [IRSN]; http://www.irsn.org) decided to profile the entire alluvial sequence with a non-cased borehole. The drilling site (Fig. 2) was chosen as a compromise between available funding and the minimum depth to the basement, as previously determined by geophysical methods. The 565-m-deep borehole passed through 535 m of soft sediments, including 15 m of sandy, pebbly fluviatile alluvium cutting into the top of a 516-m-thick monotonous, sandy-silty lacustrine clay formation, which in turn rests on 4 m of basal till with small pebbles (Nicoud et al. 2002). Fine gravel floating in the silty-clayey matrix of the lowermost 80 m indicates a glaciolacustrine environment. The basement, which was cored to a depth of 29 m, is marly limestone, rich in calcite veins, from the early Bajocian era (Middle Jurassic era). This borehole allows evaluation of the thick sediments that cause large site effects in seismic environments and contribute to the amplification of seismic ground motion (Cornou et al., 2003; Gueguen et al., 2007). To study the influences of the soil column on the ground motion, RAP decided to install three accelerometric sensors in the borehole. The first two sensors were installed at the top and bottom of the borehole. These sensors record the input seismic motion of the basin and the surface motion modified by sediments. The third is located at a depth of 42 m, below a major sediment interface. Observations systematically show strong amplification between the bottom and the top of the borehole, as well as a significant amplification between the top 40 m of sediments and the surface (Fig. 2). The records obtained since the start of the monitoring operation also provide empirical data to validate the numerical models developed to help understand site effects in the Grenoble basin.

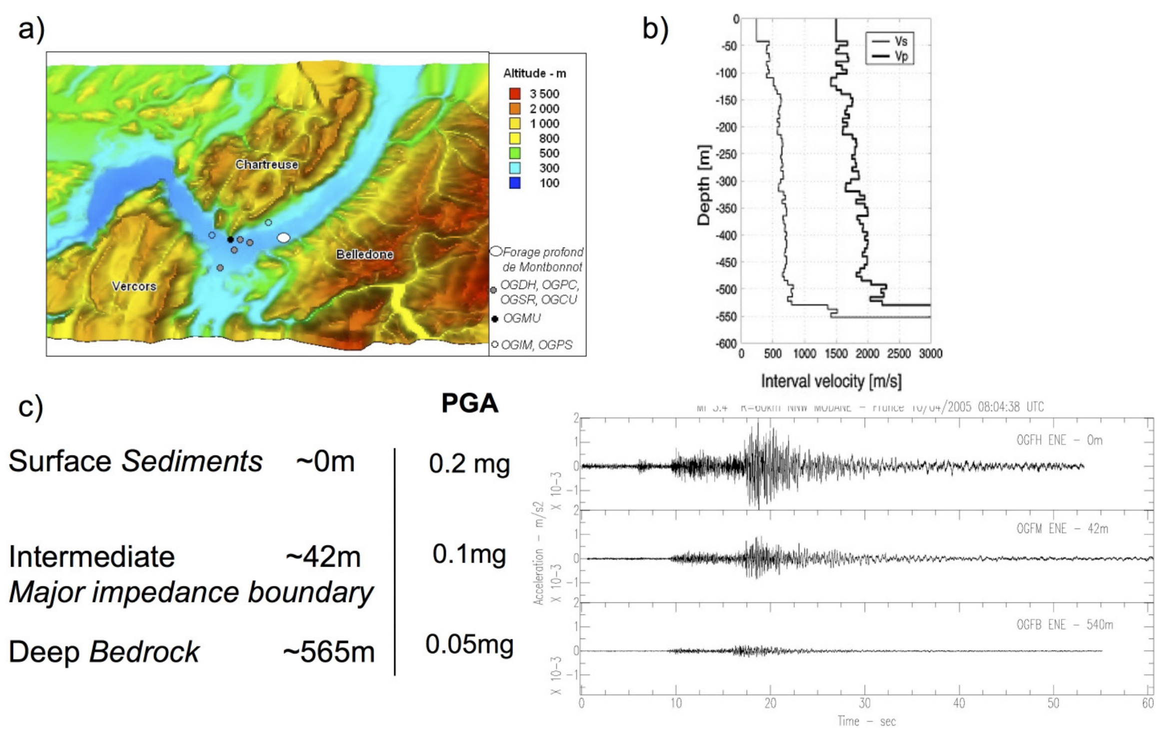

Figure 2. The Grenoble's deep borehole test site. a) Localisation of the borehole in the Grenoble Y-shaped sedimentary basin. b) Vs and Vp profiles along the borehole (after Cornou et al., 2003). c) Example of weak motion recorded at the three GL sensors

The Belle-Plaine (Martinique) shallow borehole (LIQF name)

The Belleplaine vertical array test-site is located in the Guadeloupe Island (French Antilles) close to the Caribbean subduction zone. The site was designed for liquefaction analysis in the case of sea shore sediment materials, including extensive in-situ geotechnical and geophysical surveys (drilling boreholes and laboratory testing on sample, SASW, H/V seismic noise ratio survey, seismic piezocone), pore pressure measurements and accelerometric ground motion sensors. Foray et al. (2011) performed three piezocone tests (CPTU) and installed five pore pressure sensors (Fig. 3) on the site of Belle-Plaine. The obtained measurements were subsequently analysed for liquefaction potential.

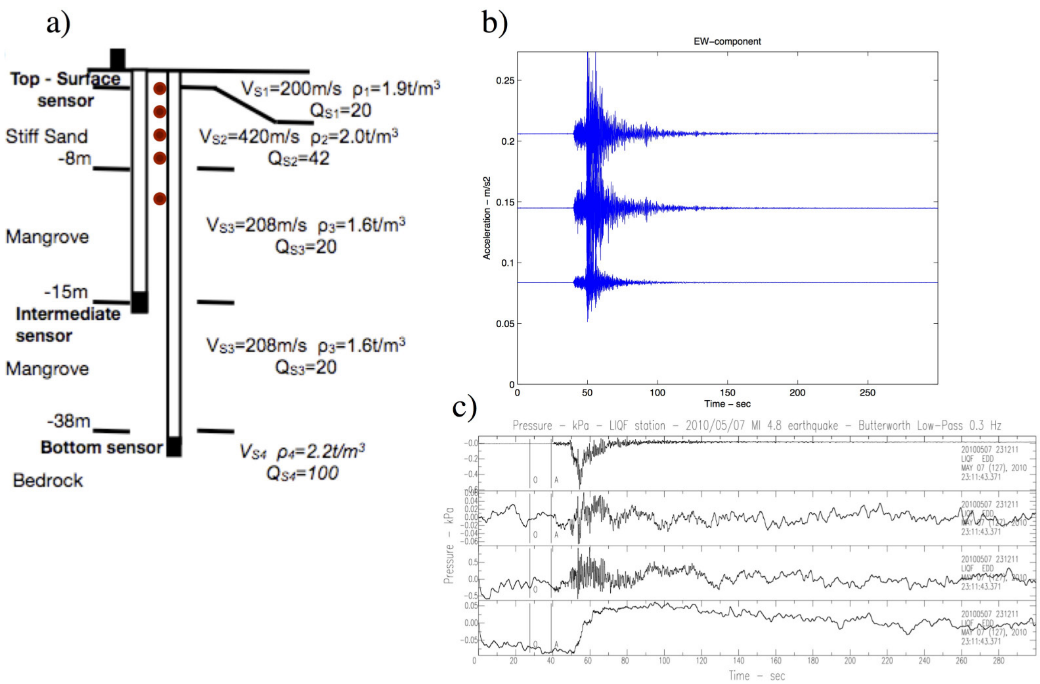

Figure 3. The Belle-Plaine (Martinique) shallow borehole test site. a) soil profile and position of accelerometer (black squares) and pore pressure sensors (red circles). b) Example of seismic ground motion recorded at the three GL sensors. c) Equivalent pore pressure measurements recorded along the soil profile.

The vertical accelerometric array is composed of three synchronized triaxial accelerometers (EST Shallow-Borehole Episensor) placed at GL-0m, GL-15m and GL-39m. All the sensors are connected to a 24-bit 9 channels stations (Kephren, Agecodagis). The sampling rate is 125 Hz and the continuous recordings are transmitted to the RAP-NDC through seelink protocol. A preliminary set of records corresponding to local and regional events and localised by the Guadeloupe Observatory (OVSG) have been recording for 6 months after the installation (Guéguen et al, 2013). It consists of recordings from 62 earthquakes, with M_L between 2 and 6.4 and epicentral distance ranging between 20 and 450 km. During the installation, the horizontal components of the instruments placed at GL-15m and GL-39m deviate 85° and 81° in clockwise direction, respectively. The maximal horizontal peak ground acceleration (PGA) recorded at GL-0m is 5 cm/s2 which corresponds to a weak ground motion, i.e. only linear seismic response is expected here. The comparison of the PGA recorded at the surface and in depth shows that horizontal PGA at the bottom (GL-39m) are around two times smaller than at the surface (GL-0m) and at intermediate depth (GL-15m). Applying the spectral ratio technique, we can show that the fundamental frequency of the soil profile is only depending on the S-wave velocity and thickness of the soft mangrove layer, i.e. 1.3Hz.

Conclusions

The RAP has now arrived to maturity and its online database, fortified by its 30000 recordings, brings essential information to the comprehension and the knowledge of the seismic hazard and vulnerability in France. The first studies undertaken on the data show that the use of low-to-moderate seismic motion gives relevant information for the prediction of strong ground motion, which is the base of the seismic hazard assessment. This is particularly confirmed by the increasing number of scientific papers and PhD thesis using these data.

The online access to common waveforms encourages and facilitates the research tasks. Because of the available common and unique database, active synergies between the partners exist illustrated by the technical and scientific meeting of the RAP organised every two years by the scientific board. This meeting gives the opportunity to see emerging new scientific problems and the end-users of the data can express the technical or/and scientific evolutions needed to increase the quality of their analysis. These discussions can direct the updating of the stations and the policy of the scientific board.

In the near future, high quality data will be selected from building and geotechnical borehole sub-networks, including analysis of specific parameters (e.g., ground motion parameters, dynamic response, displacement and strain etc....) and provided to end-users through web interface.

Acknowledgments

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References

Cornou C, Bard P-Y, Dietrich M. Contribution of dense array analysis to the identification and quantification of basin-edge induced waves. Part II: Application to Grenoble basin (French Alps). *Bull. Seismol. Soc. Am*. 2003; **93**(6):2624–2648.

Foray P, Guéguen P, Langlais M, Santruckova H, Rousseau C, Barnoud J-M, Toni J-B. Instrumentation of a sandy/mangrove site for prediction of seismic liquefaction. *Proc. 5th Int. Conf. on Earthq. Geotechnical Engng.,* 2011; January 2011, Santiago, Chile.

Guéguen P, Cornou C, Garambois S, Banton J. On the limitation of the H/V spectral ratio using seismic noise as an exploration tool: Application to the Grenoble valley (France), a small apex ratio basin. *pure and Applied Geophysics* 2007; **164**(1):115-134.

Guéguen P. Experimental analysis of the seismic response of an isolated building according to different levels of shaking: example of the Martinique earthquake (2007/11/29) Mw 7.3. *Bull Earthq. Engng*. 2012; **10**(4):1285-1298.

Guéguen P, Langlais M, Foray P, Rousseau C, Maury J. A natural seismic isolating system: the buried mangrove effects, *Bull seism. Soc. Am*. 2011; **101**(3):1073-1080.

Michel C, Guéguen P, El Arem S, Mazars J, Kotronis P. Full scale dynamic response of a RC building under weak seismic motions using earthquake recordings, ambient vibrations and modelling, *Earthq. Engng and Struct. Dyn*. 2010; **39**:419–441.

Mikael A, Guéguen P, Bard P-Y, Roux P, Langlais M. Long-term frequency and damping wandering in buildings analysed using the Random Decrement Technique (RDT), *Bull seism. Soc. Am*. 2013; **103**(1):236-246.

Nicoud G, Royer G, Corbin J-C, Lemeille F, Paillet A. Glacial erosion and infilling of the Isere Valley during the recent Quaternary. *GeÅologie de la France* 2002; **4**:39–49.

Péquegnat C, Guéguen P, Hatzfeld D, Langlais M. The French Accelerometric Network (RAP) and National Data Centre (RAP-NDC). *Seism. research Lett*. 2008; **79**(1):79-89.