

THE FRENCH PERMANENT ACCELEROMETRIC NETWORK: TECHNOLOGICAL AND PARAMETRICAL CHOICES, SCIENTIFIC GOALS AND RESULTS

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ABSTRACT

The French Accelerometric Permanent network is presented in this paper. Currently composed by more than 100 permanent stations and more than 50 associated stations, the network is characterized by various data processing (depending on the organization maintaining the stations). The data processing of the RAP stations is detailed in the paper, as the IRSN procedure used for its strong motions data. Finally significant contributions of the RAP network are illustrated particularly with two recent moderate earthquakes.

PRESENTATION OF THE FRENCH ACCELEROMETRIC NETWORK

The French territory is mainly characterized by a moderate seismicity, except for its overseas territories - the French West Indies - (Martinique and Guadeloupe) associated to the Caribbean subduction context. Nevertheless, historical seismicity for the past 1000 years and recent moderate events (Annecy, 1996, Nice 2001, Hennebont 2002, Saint Dié, 2003, Besançon 2004) demonstrate that moderate earthquakes regularly occur in France causing sometimes significant damage.

In the 80's, the French metropolitan accelerometric network mainly reflected the nuclear power plants locations. Indeed, each nuclear installation was instrumented by seismic detectors, whose seismic threshold (0.01g) was not adapted to the recording of data for scientific studies. Only few events have in fact been recorded with these instruments. Complementary to these instruments, devoted to the detection rather than the recording, few accelerometric stations were installed by scientific teams (IPSN and IPGP), located in the Alps and Pyrenees ranges. In the same time, the accelerometers installed by BRGM in Guadeloupe recorded the ground motion produced by the March 15th, 1985 earthquake at four locations. Almost all sensors were SMA1 or SMA2 analog type instruments.

In the late 80's the inadequacy of the existing network for scientific investigation and for constructing an accelerometric database was clearly noticed (Ferrieux et Mohammadioun [1]). The French Ministry of Environment decided in 1989 to promote the development of the strong motion recording in France, in order to improve the seismic hazard assessment. The network that had to be designed had two tasks: (1) to allow the recording of moderate to strong events without any saturation, (2) but as well to detect weak events in order to investigate local effects. In 1993 the preliminary phase began, initiated by the Ministry of Environment. This "testing" phase consisted in the installation in southeastern France of strong motion stations. Meanwhile the

Ministry suggested the creation of a national center to archive the data. The responsibility of this operation was entrusted to the LGIT (Grenoble).

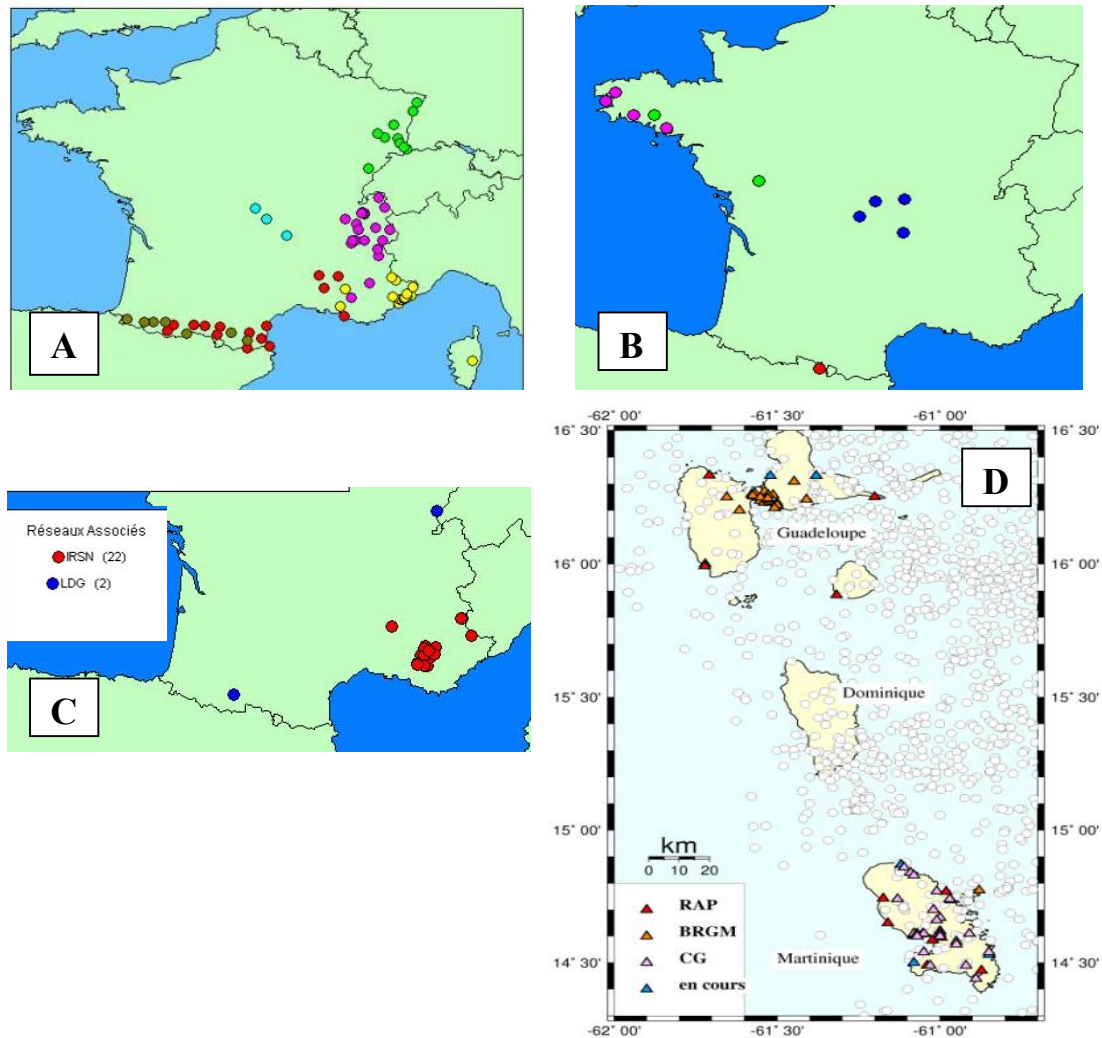


Figure 1 (after Hatzfeld, [2]): Present day locations of RAP and associated stations. Figure A: RAP stations at the end of 2003 in the metropolitan territory. Green circles: stations maintained by RAP-EOST, Pink circles: stations maintained by RAP-LGIT, Blue circles: stations maintained by RAP-OPGC, Yellow circles: stations maintained by RAP-AZUR, Red circles: stations maintained by RAP-BRGM, Brown circles: stations maintained by RAP-OMP. Figure B: RAP stations to be installed in 2004. Red circles: stations maintained by RAP-BRGM, Green circles: stations maintained by RAP-LDG, Blue Circles: stations maintained by RAP-OPGC, Pink circles: stations maintained by RAP-UBO. Figure C: Associated networks (IRSN and LDG). Figure D: RAP and associated stations (BRGM and CG General Council), and to be installed (blue triangles).

During this period, up to the year 2000's, the network mainly emphasized spectacular site effects in the alluvial Grenoble basin. This operation demonstrated the technical feasibility of a sensitive distant operated network, and the importance of such data even in cities. , The Ministry was

therefore convinced of the utility of such a network and decided at the end of 1999 to finance a permanent accelerometric network extended to the whole French territory including the French West Indies (Hatzfeld et al. [3]). The objective of one hundred stations was announced. During the following five years around 50 new stations were installed in the Alps, the French Riviera, the Rhine Valley, the Pyrenees and the Caribbean islands.

Jointly to this great instrumental effort, it was decided to formalize the collaboration of different institutions through a Scientific Interest Group (in French “Groupe d’Intérêt Scientifique” - GIS). This structure is composed of 10 partners (BRGM, CEA, INSU, IPGP, IPSN now IRSN, LCPC, UJF, ULP, UNSA and UPS), which decided to collaborate and to associate their strong motion stations to the new accelerometric national permanent network called “Réseau Accélérométrique Permanent – RAP”. The GIS is placed under the supervision of the Environment and Territory Development Ministries and the French Central Seismological Office. The aims of this GIS consist in collecting and making available strong motion data for scientists, engineers and any people interested in, and furthering the collaboration between the strong motion users of the GIS (Cotton et Hatzfeld [4]). The areas to be instrumented were defined in the convention, and yearly, new regions are proposed. One organization is responsible for each region, which means it is in charge of the network maintenance, the data collection and their validation. The central site, through modem connections, retrieves the data and stores them in the RAP database. At the end of 2003, with 91 installed RAP stations, and around twenty more to be connected, the initial goal of a hundred strong motion stations for the national network was achieved. Associated to these 91 Rap stations, records of more than 50 stations (IRSN, BRGM and General Council of Martinique) are transmitted to the central site growing the database (Figure 1). Unfortunately Figure 1 also shows the lack of stations in moderate seismic areas such as Brittany, Massif Central, where historical and recent seismicity (Hennebont 2002 earthquake) occurred. Moreover, in these areas sensitive installations do exist for which any strong motion data could be useful. Installation of future stations in these areas is planned for 2004.

Concerning the detail of the instrumentation and the strong motion records processing we do keep in mind that the RAP is made of “RAP” stations and “associated” stations, differing in instruments, in parameters chosen for acquisition and in processing. In the following sessions we will present the characteristics of the so-called “RAP stations”, and the characteristics of the IRSN associated network, composed of 24 stations.

DATA ACQUISITION AND PROCESSING FOR “RAP” STATIONS

A RAP station is composed by a sensor, which is either a Kinematics (Episensor-T) (in most cases) or a Guralp instrument, and an acquisition system specifically developed by the French company Agecodagis (www.ageco.fr.fm). This system, named Titan, has been chosen for its simplicity of use, its large dynamic range, its low weight and small physical dimensions and its low cost.

Sampling, dating, triggering parameters

The full scale of the digitizers is 2^{24} bits and corresponds to +/- 5 Volt or +/- 1 g. The electronic noise is 8 bits peak-to-peak. The analogs to digital converters are either Crystal sigma-delta CS5323 or CS5321. Analog signals are sampled at very high frequency and decimated through a cascade of FIR filters in an associated Crystal chip CS5322. A set of different sample rates is

available at the output of the CS5322 and the value of 125 samples per second is selected for the RAP. The cascade of FIR filters introduces a time delay equivalent to 1.5 sample. This time delay value is used during the data processing operation in order to cancel the phase shift of the digital filters. The data are dated after sampling and decimation filtering.

The acquisition is a triggering system (parameters in Table 1). A STA/LTA algorithm always tags the data when a STA/LTA trigger event occurs. The STA/LTA algorithm is applied to the vertical channel.

Table 1. Triggerring parameters for RAP stations

Time constant for LTA	30 s
Time constant for STA	1 s
Triggering threshold	4 or 6 depending on site
Pre-event	10 s
Trigger record minimum duration	30 s
Trigger record maximum duration	100 s

Data management

Sampled and dated data are transferred to the triggering algorithm and triggered data are added. This sum of data is then stored in the storage hardware, which is an internal 8 Mb Flash memory. The 8 Mb flash memory can be downloaded via telephone link or parallel link.

The data are stored on a “Titan Format”. It is a serial type format, constituted by an infinite sequence of information blocks (12 bytes each) alternating blocks of compressed data, time blocks and station information and acquisition parameters blocks. This Titan format is particularly well adapted for serial communication, using phone modems for example. Software associated to Titan format accept that a file begins or ends on any byte.

Table 2. Characteristics of RAP stations

Weight/ physical dimension:	4 Kg, 260 x 160 x 120
Power requirements:	11.5 – 18 Volt, 2.5 Watt
Input voltage full scale:	+/- 5 Volt
Input impedance:	25 Kohm
Digitizers:	Crystal CS5321+CS5322, sigma-delta, 24 bits.
Overall digital noise:	8 counts p-to-p.
System clock stability:	5 10 ⁻⁷
External time reference:	DCF radio receiver.
Data time stamp:	internal time (running freely, never synchronized) + external time.
Data storage:	trigger records saved on internal 8 MBytes Flash memory
Communication:	serial RS232, to modem or PC

The station consumption is 200 mA, without communication, with a supply voltage between 12 and 15 Volts, and around 470 mA during communication period, including 110mA for the sensor. Table 2 summarizes technical characteristics for RAP stations.

Data processing and formatting

The data processing is linked essentially to a quality control (in time and evaluating the signal to noise ratio) and finally transforming the Titan format into a storage format used for the dissemination of the data. This processing is under the responsibility of each regional center. The software used is a Titan package including various independent codes associated to the Titan format running on Unix operating system. These codes enable the conversion into very common formats such as SAC, Ascii, Segy, Sismalp (French velocimetric network format), binary, Miniseed and Seed. The choice of the format for storing the data is a “regional center” decision (in most cases is SAC or Titan format). These data are periodically transmitted to the Grenoble RAP Central Site , which responsibility is to put them on disposal through a web site.

Data processing on raw data consists in the suppression continuous component (offset) and the conversion of numerical units into motion units (generally m/s/s or mm/s/s. The offset correction is applied using a SAC procedure applied in the Central RAP Site. The instrumental transfer function being a constant, in the frequency range of interest, no instrumental correction is applied. Each regional center stores complete station information i.e. site conditions, sensor references and acquisition parameters in its databank.

Communicating and retrieving data from rap stations

Titan Rap stations are called (by regional center) and parameterized through phone modems using the “Inter” code that was developed by the French geophysical community on the Unix operating system. This remote control system can be manually done or automatically with shell scripts and Unix system.

Stations are called once a day and only events that are interesting for seismic studies are downloaded at the central site, in order to limit phone call durations. The procedure for retrieving those events is applied to all RAP stations and is summarized as follows:

- Interrogating the national seismological data centers or local centers in order to list events detected the previous day,
- Interrogating the RAP stations to get the list of records
- For each station, the list of the records that have to be retrieved is obtained by correlating the time indexes in the two above mentioned lists,
- Interrogating the RAP stations for downloading the selected data. The status of the station is given at the end of process.

In case of seismic alert an operator triggers a data collection procedure. Data are retrieved within ten minutes, if there is no phone line weakness or breakdown.

DATA ACQUISITION AND PROCESSING FOR IRSN STATIONS

In the early 90's IRSN installed a dense velocimetric and accelerometric network around the Moyenne Durance Fault (southeastern France), which is historically speaking one of the most active faults identified in the Metropolitan territory. IRSN strong motion stations were installed, complementary to the velocitometric network, in order to record motions in case of significant event that obviously would saturate the velocity stations. This states the clear difference between RAP stations (detecting very weak motions) and those of IRSN, restricted to capture strong motions.

Acquisition systems of IRSN stations

Acquisition systems of IRSN strong motion network are K2 or Etnas made by Kinemetrics (Table 3).

Table 3. Acquisition system characteristics of IRSN stations

New K2 with internal Episensor	dynamic >114dB for 200 sps
Ancient K2 with internal FBA	dynamic >110dB for 200 sps
Etnas with internal Episensor	Dynamic: 108dB for 200 sps

Using Etnas only the triggering acquisition is possible, with threshold including a “classic strong” filter and final anti-aliasing filter (non causal). Depending on the stations, FBA or Episensors equip IRSN stations. All recent stations have an internal Episensor sensor (Table 4) .

Table 4. Characteristics of IRSN sensors

Internal FBA23	Characteristic frequency: 50Hz, damping 70%, dynamic >135dB from 0.01 to 50hz (>145db from 0.01 to 20hz).
Internal Episensor	Frequency range 0 to 200Hz, dynamic >145dB

Acquisition parameters, processing, data characteristics

Parameters for IRSN strong motion data acquisition are summarized in Table 5.

K2 and Etnas automatically correct the delays caused by this filter.

Recording starts when the threshold is reached for one component (same weight for each component). Thresholds for triggering and de-triggering are identical.

Table 5: IRSN stations acquisition parameters

Sampling	200 sps
Frequency range usable for data	40% of the sampling using digital anti-aliasing filters, ie [0 to 80Hz] for 200 sps.
Final anti aliasing filter	no causal, linear response for the phase, pure delay, no distortion for the acceleration signal phase.
Triggering with a threshold	0.5 to 1mg depending on the stations
Filter linked to the trigger	IIR Bandpass filter : classic strong [0.1Hz-12.5Hz] with 200sps

Data processing for the IRSN accelerometric records

The processing of IRSN data is the standardized method proposed by Kinemetrics software package (Application of the Strong Motion Analysis for computing corrected accelerograms V2 format): opening of the event file recorded by a K2 or Etna acquisition system (.EVT),supression of the continuous component (IRSN process evaluates the offset considering the entire event file), writing IRSN raw data in CDMG format (V1 File).

To obtain the corrected acceleration time serie (V2 File)

This step allows (Figure 2):

- Removing the offset (baseline correction) and the instrumental response of strong motion data (processing of V1 File).

- Computation, by integration (including a high pass filter), of the velocity and displacement time series.
- Writing the data in chosen format (**CDMG**)

- **Instrumental Correction:**

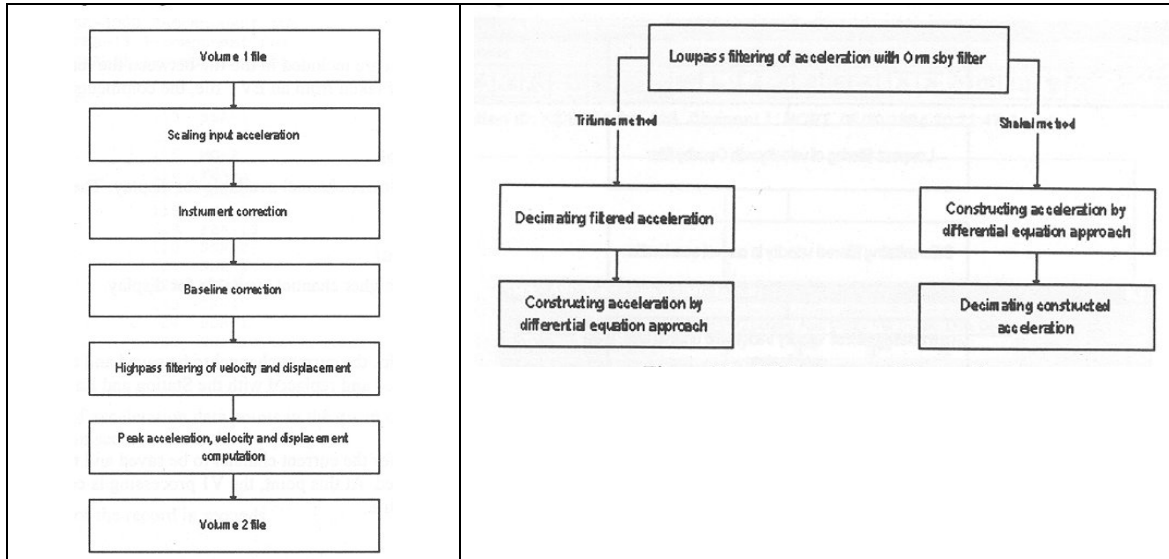


Figure 2 (Kinematics [5]): (left) Overall processing (V2), (right) instrument correction

The processing data code allows the choice between 2 methods for correcting the instrumental response : Trifunac method or Shakal & Ragsdale method. IRSN data are processed using Trifunac method.

- **Baseline Correction:**

The following scheme (Figure 3 left) is used for correcting the offset (with the Trifunac branch for IRSN process).

All these corrections, performed using SMA code, need some parameters to be defined (Table 6 with IRSN parameters indicated in brackets).

After this complete process the V2 file is obtained and saved.

From V2 file type, all data are saved under several formats: ascii 2 columns, Sac ascii (for RAP central site), Sac linux (for RAP central site), Sac sun. All IRSN strong motions are regularly transmitted to the RAP central site, stored in the RAP database and available through the RAP website, in the same way as other strong motions recorded by “RAP” (<http://www-rap.obs.ujf-grenoble.fr>).

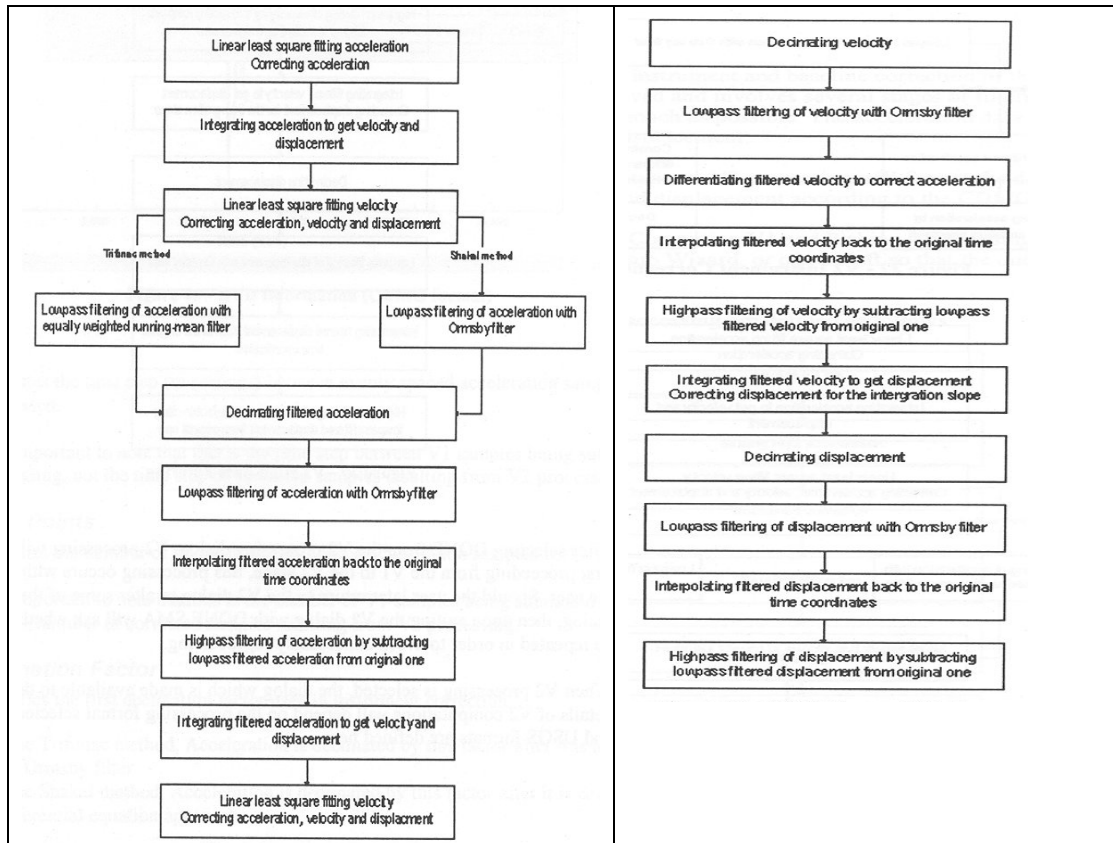


Figure 3 (Kinematics [5]): (left) baseline correction, (right) high-pass filtering (V2)

Table 6: IRSN choices for processing the data

1st decimation factor (instrumental correction)	[1] keeping the maximum number of samples for corrected data
Half length of filter operator: low pass filter for offset correction,	[10]
Acceleration decimation factor: high pass filter of acceleration during the offset correction,	[10]
Velocity decimation factor: high pass filter of velocity for the high-pass filter step,	[10]
Displacement decimation factor: high pass filter of displacement for the high-pass filter step,	[10]
Terminal frequency: final frequency of the Ormsby low pass filter (instrumental correction)	[50]
Roll-off width: width of the Ormsby low pass filter (instrumental correction)	[3]
Corner frequency : corner frequency of the Ormsby high pass filter (offset correction and high pass filtering of velocity and displacement)	[0.25]
Roll-off width of the Ormsby high pass filter (offset correction and high pass filtering of velocity and displacement)	[0.1]

PRESENTATION OF SOME RESULTS PROVIDED BY RAP STATIONS

This section illustrates the contribution of the strong motion network installed in France and, the availability of accurate data through a web site using 3 examples.

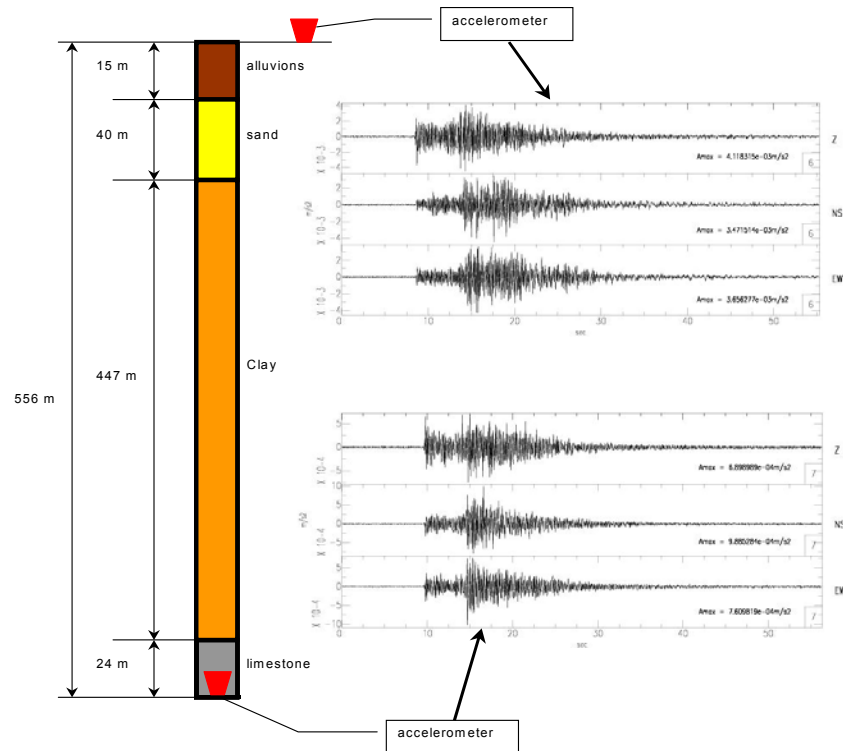


Figure 4: Grenoble borehole strong motion stations. On this example, the motion recorded at surface is ten times greater than the one in depth (top 3 accelerograms: y scale in 10^{-3} m/s^2 ; bottom 3 accelerograms: y scale in 10^{-4} m/s^2).

Significant site effects detected on weak motions in urban context: Grenoble, deep borehole measurements

A significant result of the RAP network is the highlighting of site effects especially in the Grenoble basin. The installation of five stations in this basin, which is an old glacial valley filled by more than 500 meters of sediments (reaching 900 m in the deepest part of the basin), allowed the observation of very strong amplification within the basin, with respect to the bedrock (Lebrun [6]). These amplifications have been observed on weak seismic motion, reaching a maximum factor of 15 on a frequency range between 0.3 and 5Hz, depending on the station location in the basin (Figure 4). This frequency range concerns most of the buildings constructed in the area, explaining why these constructions regularly start resonating during local, regional and distant earthquakes. These results have had an important consequence for the nuclear power plant safety regulation, which was under a revision process from 1995 up to 2000. The evidence of such very strong site effects on the seismic motion conducts the French Authority to approve the introduction in the new code (which is a guide to assess the seismic hazard for the NPP safety) of a session dedicated to such effects. In case of such geometries or really important sediment thickness, the seismic level cannot be evaluated using the attenuation relationship with a “soil site coefficient” only associated to a V_s 30 value. The new nuclear code, in such configuration requires specific study to quantify the impact of the site on the seismic motion.

Besançon Earthquake (23/02/2004)

A $M_I=5.1$ event occurred on the 23rd of February 2004, twenty kilometres away from Besançon (latitude 47.29° North and longitude 6.27° East, Figure 5). These magnitude and location estimations come from RéNaSS, which is the organization responsible for the Seismic Alert on the French territory. RéNaSS also estimated the focal depth to be 10 km. Two strong historical earthquakes occurred in a 100 km radius around the 2004 Besançon event epicenter, the Bâle (1356, macroseismic magnitude of 6, depth 10km – IRSN) and Remiremont (1682, macroseismic magnitude of 5.9, depth between 10 to 15 km - IRSN) events (Volant et al. [7]). The day after the earthquake, the strong motion data recorded by RAP stations were available on the Rap WebSite. The regional RAP center (Rhénan Fossé) maintains 10 RAP stations in the epicentral area: all stations recorded the event. The Alps regional Rap center manages around twenty stations, which also triggered. Figure 5 (left) locates the RAP stations that recorded this event, indicating the focal mechanism determined by ETH -Zürich.

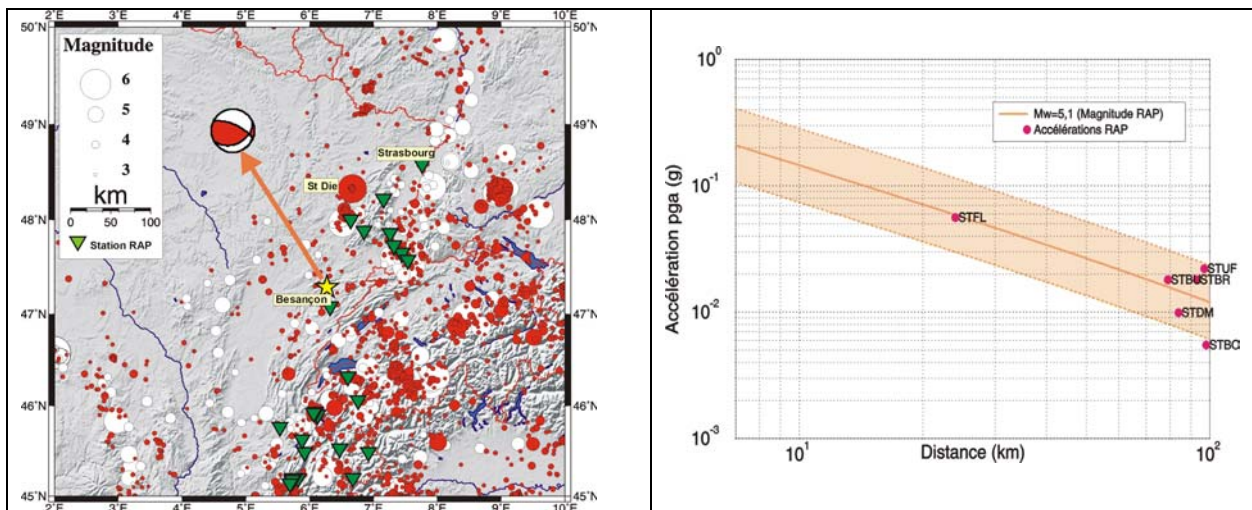


Figure 5 : (left) Location of the 23/02/2004 event epicenter (yellow star). Red circles for instrumental seismicity (1962-2000 LDG Catalogue) and white circles for historical seismicity (around 1000 years). RAP stations are represented by green triangles. (Right) Comparison between PGA from Rap data and prediction (Berge-Thierry et al. [8] attenuation relationship, soil condition, mean value with standard deviation).

Using three of the RAP stations (OGTB, OGMA and OGCH respectively located at 111, 178 and 202 km from the epicenter), IRSN evaluated a preliminary moment magnitude of 5,1 (Volant et al., [7]). We then compared the peak ground accelerations recorded by RAP stations with the predicted values using the most recent attenuation relationship used for French seismotectonic context (Berge-Thierry et al [8]). This relationship was established considering the M_s scale. Figure 5 (right) presents the comparison. No conversion was applied i.e. the assumption $M_s=M_w$ was made. The recorded data are in good agreement with predictions.

The Besançon event illustrates the importance of supporting a broad strong motion network, even in a moderate seismic context. Strong motion data are systematically compared with existing attenuation relationships to improve them, the aim being to develop pure “French” relationship, avoiding the use of data too scattered with respect to their geodynamical or geological context. But to reach such a goal, the RAP network should be extended to the whole

territory (completing uncovered areas) and this network has to be maintained for a long time to get a good distance to magnitude records distribution, which is the minimal condition to derive attenuation relationship.

Saint Dié Earthquake (22/02/2003)

A MI 5.8 (LDG), MI=5.4 (RéNass) event occurred on the 22nd of February 2003 and was located 80 km west of Strasbourg (Volant et Lemeille [10]). This event triggered all the regional RAP stations (Figure 6). This event was thoroughly studied by IRSN because it was regionally strongly felt especially in the Fessenheim nuclear power plant. This event did not trigger the Fessenheim instrumentation, probably because the sensor of the detection system (triggering above 0.01g) was located inside the structure. This study should encourage the nuclear operators to separate their free field sensor from the detection system (Dervin [11]). If the free field sensor of Fessenheim was of the alert system, seismic motion above 0.01g should have been recorded at the nuclear site, as clearly suggested by the RAP data (Figure 6).

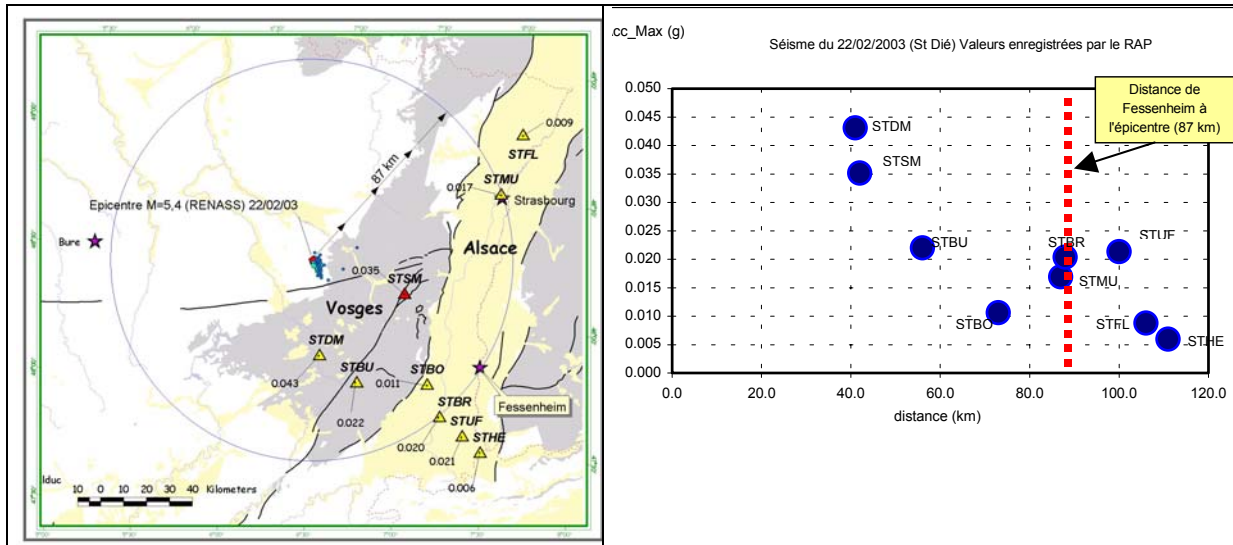


Figure 6 (from Berge-Thierry et Cushing [9]): (Left) Location of RAP stations (yellow triangles for “soil” stations, red triangles for “rock” stations). The circle shows the 87km radius from epicenter crossing the Fessenheim NPP site. Maximum acceleration is indicated near the station symbol (in g). (Right) Maximal acceleration versus distance.

CONCLUSIONS

This paper presents the French Accelerometric Network, composed by RAP stations and associated stations. In the framework of the workshop we specified the data processing of the RAP stations and for IRSN associated stations. The paper is not exhaustive as the processing for other associated networks (i.e. the BRGM, LDG and General Council of Martinique) is not described. The necessity of maintaining a strong motion network even in a moderate seismic country was illustrated in the paper.

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