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SYTMIS: SOFTWARE FOR REAL-TIME MICROSEISMIC MONITORING SYSTEMS

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ABSTRACT

In order to apply the microseismic monitoring concept to study mechanical instabilities of rock masses, INERIS developed SYTMIS, a comprehensive software package to design very low-cost but high performance, digital, monitoring and back-analysing systems, based on standard PC and/or workstation technologies. Designed to fulfil most field situations, SYTMIS also permit multiple monitoring from an unique central site, whether as a standalone computer or local area network. The paper describes in more details how controlling seismic regime of rock masses is important, how SYTMIS works and some of its current applications.

1 - INTRODUCTION

Any redistribution of stresses (of mechanical, thermal, hydraulic origin) in a rock mass can result in irreversible deformations of the rock matrix and in anelastic readjustment of pre-existing discontinuities. It is possible to draw a distinction between quasi-static (or aseismic) deformations and dynamic deformations for which part of the elastic energy released by the fracture is propagated in the form of transient waves detectable over a very broad frequency spectrum usually ranging from 10 Hz to 200 kHz. We speak then of microseismic or seismo-acoustic activity. The microseismic activity of rocks is a phenomenon which, typically, can be observed in unstable rock masses or those under high stresses. Checking alone of measurements of quasi-static deformations cannot then be considered to be sufficient (see Fig.1).

Remote microseismic or seismo-acoustic monitoring in real time is a fundamental approach in such varied fields as:

- the monitoring of rock masses and local subsidences: extractive industries, hydrocarbon fields;
- underground gas-storage reservoirs, radioactive waste;
- studies of seismic risks, monitoring of reservoirbasins;
- engineering of geothermal fields and fluid injections;
- monitoring of unstable slopes and embankments;
- laboratory tests.

The study of acoustic signals provides unique information on the damage to rocks and underground workings, providing a lot of interesting material not accessible by observation. The recording and analysis of seismograms takes account of:

- the location and intensity of the fracturing produced;
- the behaviour of the pre-existing discontinuities;
- the transfers of stresses in the zone concerned;
- damaging mechanisms;
- the prevention of instability phenomena.

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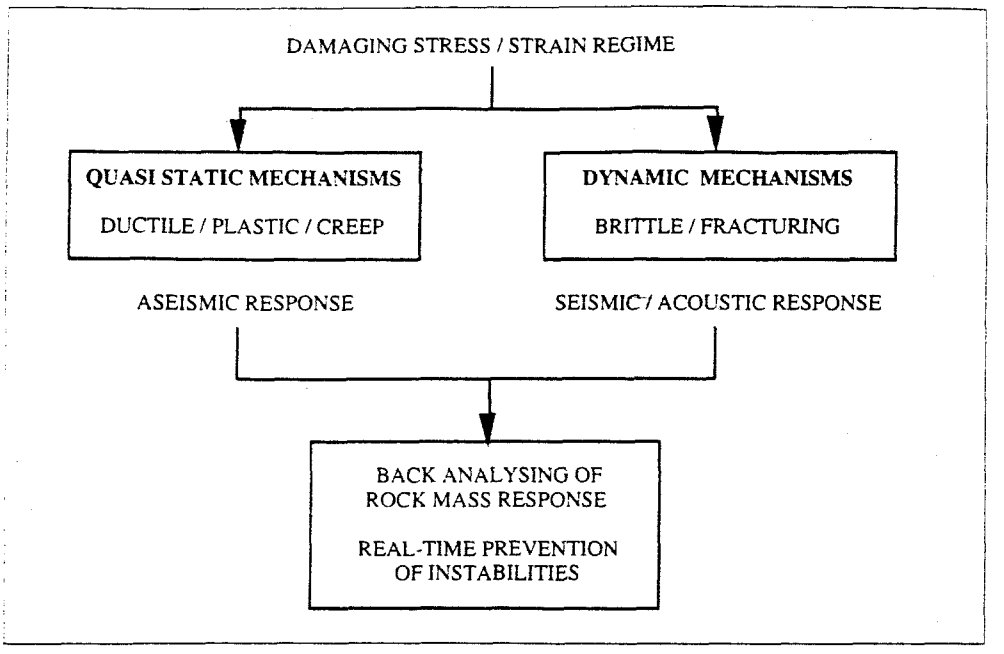


fig. 1 : Studying large strain behaviour of rocks means dealing with their seismic response. Both high quality, real-time digital monitoring and back analysis of rock mass seismic response are needed for comprehensive understanding and assessment of small/large scale failures mechanisms.

2 - REMOTE MICROSEISMIC MONITORING NETWORKS

In practice, a remote microseismic monitoring system usually comprises (see Fig.2):

1- A network of vibration transducers of the geophone, accelerometer or hydrophone type, characterised by two parameters, impedance and sensitivity, and whose output signal is proportional respectively to the velocity, acceleration or pressure of the transducer concerned. The choice of a particular type of transducer depends mainly on the amplitude and frequency of the signals expected.

2- A signal conditioning and transmission unit comprising elements such as preamplifiers, amplifiers, filters for the conditioning part, insulators, modulator/demodulator, cable, transceiver for the transmission part.

3- A digital data acquisition and processing centre. Depending on the type of application the interpretation may comprise a simple record of measurements of particular velocities produced at a temporary station (studies of vibrations/blasts).
For the most complex applications the system must be able to handle complete and real-time processing of the seismograms recorded by a network of several dozen stations distributed on one and the same site, including analyses of location, amplitudes and management of alarm criteria. In this case, the management of the database as well as the optimum distribution of the automatic or interactive processing tasks on the data-processing network shall permit industrial integration of the software in standard hardware environments.

In order to satisfy all the objectives and quality requirements of remote seismic monitoring in real time, INERIS has developed the SYTMIS software system. The main characteristics of SYTMIS are as follows:

1- Because it is compatible with the Windows 3.1 (16 bits)/ NT (32 bits) and UNIX/X11 environments, SYTMIS makes it possible to convert any compatible PC computer into a powerful microseismic acquisition centre which is fully programmable and able to be adapted for any type of transducer and vibration measurement networks.

2- SYTMIS provides optimum modularity for the automatic processing of microseismic events. It enables the automatic printing out of personalised graphic reports (any type of evaluation of measurements and seismic activity for the zones of interest, real-time alarm reports, ...).

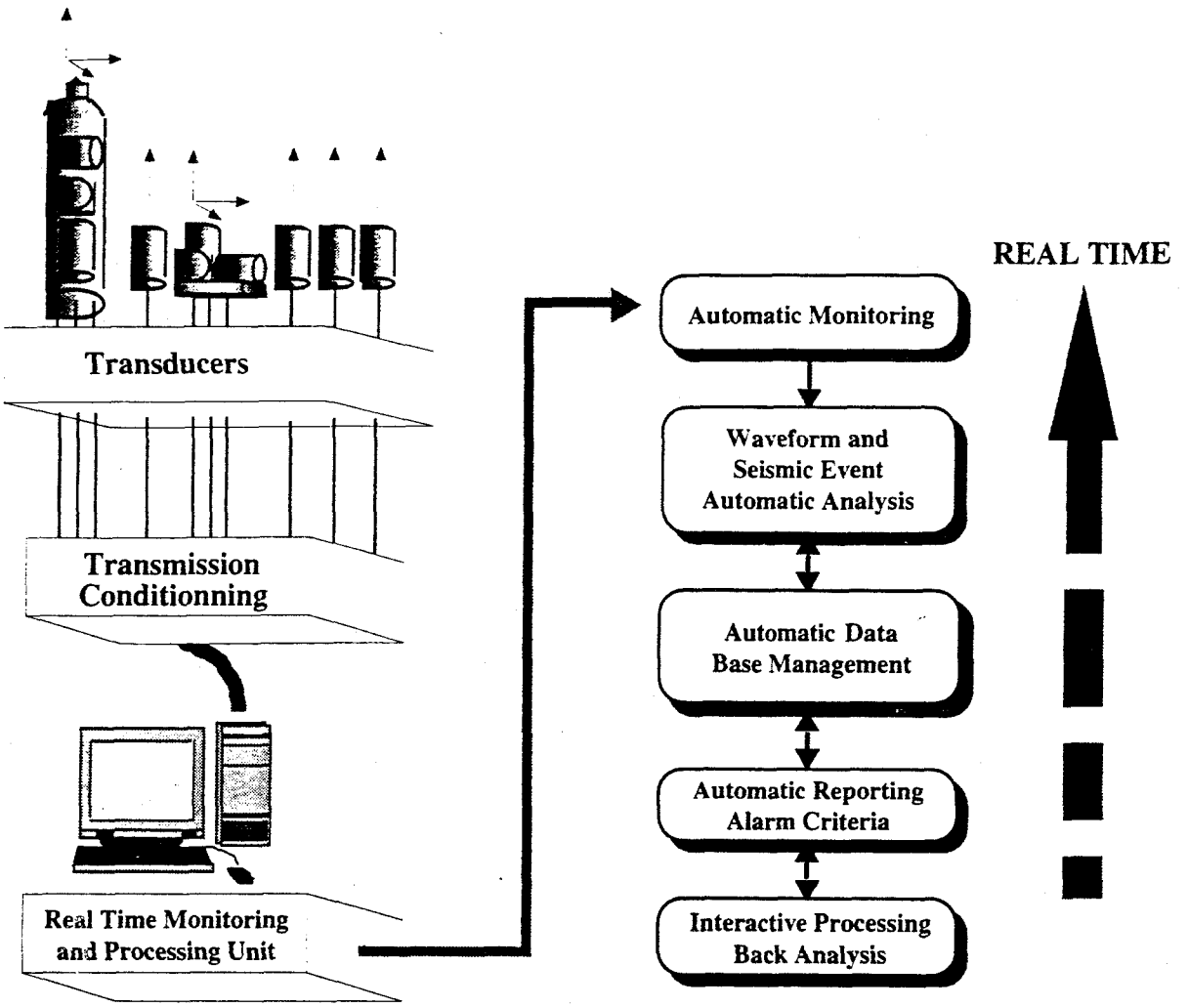


fig. 2 : microseismic monitoring applied to rock failure prevention or back-analysis : high quality, real time systems must handle automatic reporting including last event occurence analysis, large sequences preceding and 2D/3D mapping based on proper, triggering criteria defined for the area of interest.

3- SYTMIS offers every graphic facility for interpretation of the measurements, calculations and results for a back-analysis of the seismic regime of the zones of interest.
4- SYTMIS makes it possible to manage several remote monitoring networks from a central site. The automatic management of the databases permits optimum utilisation of these resources from a central computer in the local data-processing network.

3 - MAIN CHARACTERISTICS OF SYTMIS

SYTMIS is a package of integral and modular software based on the very latest data-processing architectures (C and C++ programming languages, Windows 3.1, Windows NT (32 bits), Unix-X11 environments). SYTMIS has been designed for total portability to electronic hardware whose standards, in terms of performances and costs, are in a constant and rapid state of evolution.

SYTMIS comprises eight modules, namely :

- SYTMIScop : data acquisition. Driving one or more A/D boards depending on PC slots available, number of channels to be linked, and sampling frequency, it allows for «intelligent»

response of seismic network, thanks to a complete, triggering controller. SYTMIScop is fully featured for high reliability, digital seismic monitoring for most field situations, ranging from laboratory testing to macroscale networks.

- SYTMISauto : automatic waveform and seismic event processing. Integrating many built-in, easily adjustable functions, it offers all conventionnal calculational procedures such as P/S arrival-time pick-up, location and errors estimates (multilayered, inclined velocity model integrated), amplitude, magnitude, energy, power and spectral analysis for both «on-line» or «off-line» processing.
- SYTMISview : interactive waveform and seismic event processing. It offers a high level graphic interface for displaying and analysing waveforms, for fast validation of calculated parameters or more specific in-depth studies.
- SYTMIScom : easy-to-use command and computing language for automatic batch processing of seismic data and generating graphic reports. SYTMIScom gives access to selected stored events and user's own procedural calculations using SYTMIS predefined variables.
- SYTMISbase : scientific and statistical analysis of seismic data. It incorporates a full range of interactive functions for searching, extracting and displaying data related to seismic events, and proves to be a powerful assistant for most routine investigations or in-depth research in seismic event parameters and sequences.
- SYTMIS4D : space-time graphic display of hypocentres with representation of structures probed. It constructs multi-windowed, space-time dynamic animations you need to understand interactions between rock mass and industrial/experimental activity.

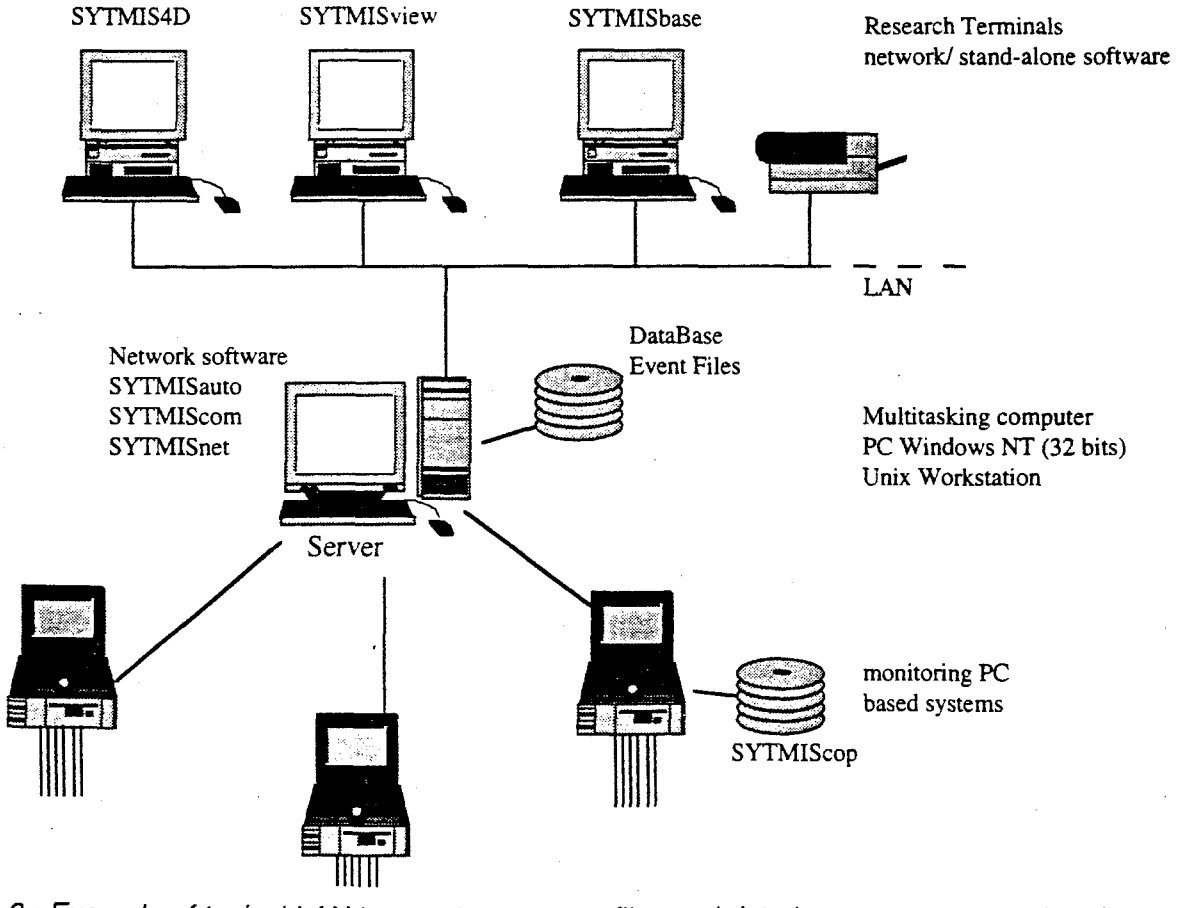


Figure 3 : Example of typical LAN integration : events files and data base are processed and stored on central computer. Event files contains seismic network and processing parameters, results and waveforms. Data base contains seismic network and processing parameters and results. SYTMIS offers full modularity to accomodate central site situations and needs.

- SYTMISpair : detection and processing of seismic doublets.
- SYTMISnet : remote control of monitoring systems and microseismic sub-networks. It allows you rational control of on-site stations and collected data from central site.

Since SYTMIS ensures dynamic loading/tracking of network, processing and calculated parameters from both database and event files, only two configuration files are needed for the whole environnement to be run : one for the acquisition unit, and the other for automatic processing. This architecture ensures safety and easy retrieval of used parameters at any time (report printout, parametric studies, reprocessing of data on standalone computer,...).

4 - EXAMPLES OF SYTMIS APPLICATIONS

4 - 1 Real-time seismic monitoring of deep coal mining

The seismic network of the Provence U.E. mine consists of 9 seismic stations (geophones, 15 channels) distributed at the surface and underground over a radius of about 2.5 km around the central site. The remote seismic monitoring makes it possible to track, in real time, the tremors generated by the advance of the working fronts located more than 1000 metres underground. Depending on the rate of advance, more than 100 seismic events of a local magnitude between 1.4 and 3.2 may be recorded every day. To compensate for the saturation of the signals for events of magnitude less than 2.7, several stations are equipped with dual-gain channels providing better dynamics of the network (15 channels in total).

The automatic data acquisition and processing system is based on the SYTMIS software environment (see Fig.3). The acquisition centre consists of two PC/386 compatible type computers, situated in parallel, which in their turn perform the data acquisition in a master/slave logic system. The Master/Slave communications protocol, integrated in SYTMIScop offers optimum reliability in the event of a breakdown or disruption of one of the two PCs. Each acquisition unit is equipped with a 16 channel/12 bit card. Triggering is initiated when the threshold is exceeded in at least three stations in a time window of 1.5 seconds, with a sampling frequency of 155 Hz per channel.

The real-time transmission of the files to the server machine provides access to the data on the

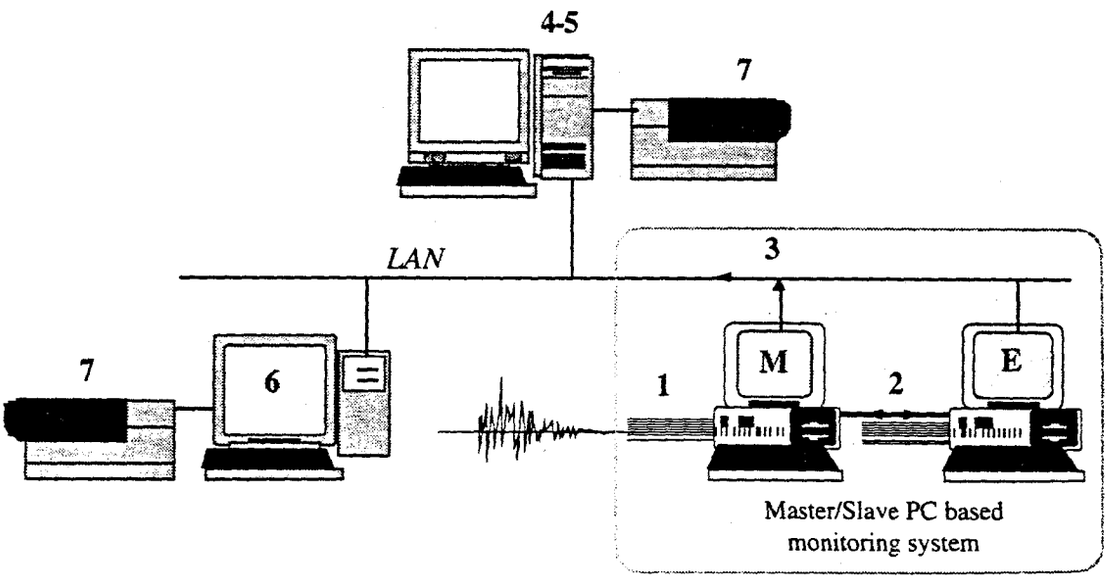


Fig.3: Automatic data acquisition and processing system in operation at the Provence U.E. mine: 1) Event detected, 2) Acquisition, changeover into slave mode, pre-processing of data, 3) Transmission to multitasking machine, 4) Wave pickup, locating and amplitude calculations, 5) Automatic storage and updating of database-oriented files, 6) Interactive processing and validation of the data, 7) Printing of reports.

local data-processing network (Ethernet type). Complete automatic processing of the seismic event is executed immediately, making it possible to carry out location, magnitude and energy calculations. The sedimentary basin is fixed by means of a digital velocity model with four main layers (Senfaute et al., 1994).

All configuration parameters, seismograms and results of signal amplitudes and spectra are recorded in the event file. The calculation parameters and the results are updated in the database.

Interactive processing from any terminal of the local network can be connected a few moments after acquisition for verification of the calculated parameters. Rapid identification of the quality of the automatic pickups of wave arrival times is based on the evaluation of an indicator comparing the results by STA/LTA and neural networks, integrated in SYTMISauto (Bigarré & al, 1995).

The advantages of this configuration are many. We can note in particular:

- the acquisition of data from a dual centre (Master/Slave protocol) ensures optimum reliability,
- the centralisation of the data, in real time, on the server machine permits instantaneous response to the characterisation of each event,
- the centralised access to the database broadly meets the information distribution requirements for the different operators.

A similar configuration is being developed for the Houillères du Bassin de Lorraine mine for a remote seismic monitoring system of 15 stations (21 channels) located at the surface and underground.

4 - 2 Seismic monitoring of open pit slopes

Since 1987 the coal at Carmaux, Tarn has been mined by open-cast methods. The purpose of the working of the Sainte-Marie find is to recover the coal from the barrier of the former main pits which would open up the former underground mine with 9 main seams whose thickness varies from 0.5 to 8 metres (see Fig. 4).

Apart from the presence of former underground workings underlying the current pit, the complexity and size of the local fracturing of the basin, as well as the heterogeneity of the mechanical characteristics of the carboniferous materials encountered have been the main factors causing a number of instability problems observed with slopes with a mean height of 12 metres.

The development of certain flanks of the pit requires therefore an overall method for the monitoring and inspection of configurations liable to slippage - a method in which instrument surveying assumes considerable importance. The various surveying methods used are:

- topographical surveying by theodolite,
- breakable surveying tubes,
- «Tensmeg 70» strain gauges,
- inclinometer tubes,
- multi-point extensometers with «WR-FLEX» rods.

4 - 2 - 1 Trials with remote microseismic monitoring

During the end of 1994, in close collaboration with U.E. Tarn mine, INERIS installed an experimental seismo-acoustic monitoring network making it possible to obtain an accurate answer to the following questions:

- does mechanical degeneration of the local zones situated in the rock masses give rise to seismo-acoustic activity ?
- what impact do mining explosions have on the stability of the flanks in terms of dynamic stresses and particular velocity ?

The aim of this methodological approach is to evaluate the potential contribution which remote seismo-acoustic monitoring can make to the surveillance of slumps and to assess its complementarity with the operational devices described above.

4 - 2 - 2 Description of the experimental network

In the North-East corner of the Saint-Marie pit, underlying the main fault 220, three seismo-acoustic

stations have been installed: two vertical monoaxial stations and one tridirectional station. A supplementary vertical station of the low frequency (2 Hz) type was added to the network to record the low frequency vibrations induced by daily blasting (see fig 4 & 5).

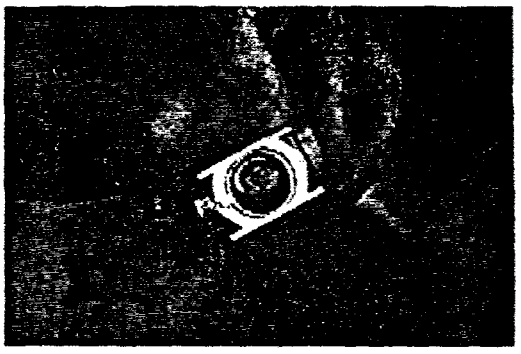
Each cabled station (coaxial screened) is connected to an Algeco (mobile cab) positioned at the apex of the sounded zone (approx. 350 metres); this is air-conditioned and equipped with three telephone lines. The Algeco accommodates the conditioning hardware and the signal detection and acquisition centre. The entire equipment forming the acquisition unit is supplied by an insulating transformer connected downstream from a mains filter.

Because the particular velocities expected are very low, the signals issued by the transducers have to be electrically amplified for them to be compatible with the +-5 V input of the acquisition card inserted into the PC compatible computer. Six two-stage pass-band amplifier filters are used. The filtering thresholds are controlled over a 60-950 Hz band for the 100 Hz stations and over 2-50 Hz for the low-frequency transducer.

The outputs pass through a terminal board equipped with electrical insulators, connected to the acquisition PC. The latter, which is of the portable 486 DX2 66 type with 16 MoRAM, 130 MoDD, is equipped with the following features: a RTI 860 12-bit analogue-digital conversion card, 16-channel

Fig. 4a :triaxial probe to be cemented in vertical borehole.

Fig. 4b : close view of "Pajari" device to recover azimutal orientation of 3D probe after installation.



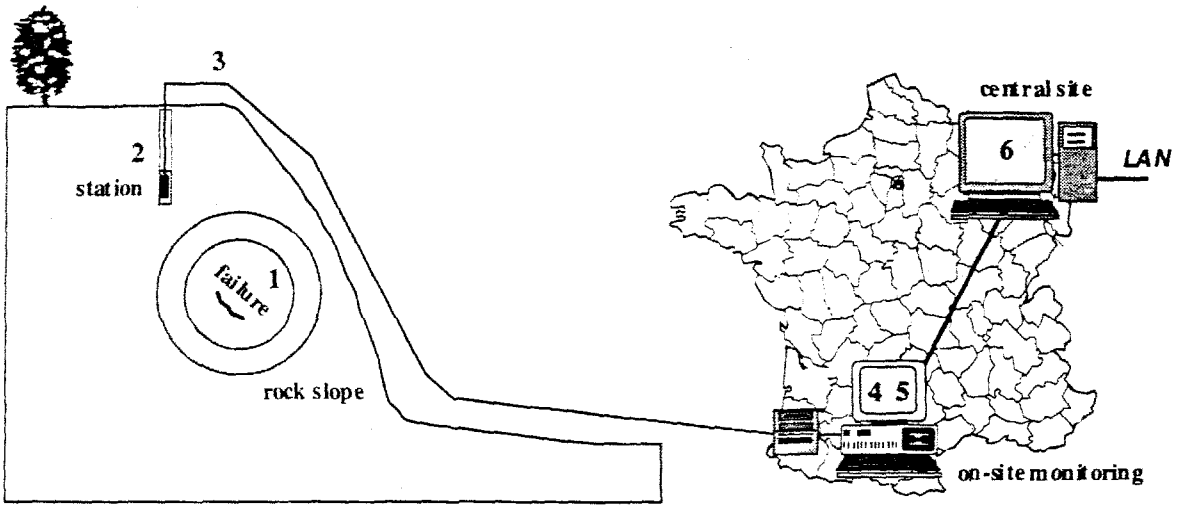


Fig. 5 : shematic of the remote, monitoring system with automatic, daily transmission to central site.

5 V Analog Devices, DOS/Windows 3.1, and the SYTMIScop software which drives the card, i.e. the scanning of the input signals, the detection, recording, storage and transmission of the files. The sampling frequency is 5000 Hz per channel, with an acquisition time of 2.5 seconds for complete recover of signal from blasting. An automatically operated modem (9600 bauds) permits daily transmission of the data to the processing location at Nancy via the standard telephone network.

5. CONCLUSIONS

Microseismic monitoring is used in many natural or industrial fields concerned with rock mechanics and rock mass failure. However, design and cost of installations, as well as lack of human resources to process and analyse seismic data is of the utmost importance in most projects.

SYTMIS represents the state of the art microseismic measurement software applied to digital, real-time monitoring. Fully compatible with very standard computers, it is developed in several , modular, integrated modules based on recent environments as Windows NT, offering a major technological advance compared to standard applications.

SYTMIS permits fast adaptation for a wide range of macro/microseimic applications, while providing all features needed to analyse in-depth, large seismic data banks. SYTMIS accomodates from one to dozens of stations, subdivided into one or several subnetworks. Stations might comprise one or several sensors, each of them providing one or several channels with selected sensitivites for high dynamic range. All calculation procedures are programmable. It manages remote control of on-site acquisition units from host computer, even from standard phone lines, which is a very key point for low-cost, remote operating systems.

SYTMIS is already installed on different sites, ranging from routine analysis in the mining industry to hydraulic fracturing acoustic emission or rock slope instability problems. SYTMIS is a software technology that benefits constant efforts in improvement and upgrade.

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