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MEXICO CITY SEISMIC ALERT SYSTEM

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Abstract: The Valley of Mexico suffers the effects of the seismic activity generated by subduction of the Cocos Plate under the North American Plate. Major earthquakes (M<7) have caused severe damages to Mexico City like the one of September 19, 1985. The occurrence probability of an earthquake M<7 before the year 2000 is very high. For this reason and taking advantage of the radio wave velocity, a real time Seismic Alert System (SAS) for Mexico City, capable of announcing 60 sec before the arrival of earthquakes from the Guerrero Coast has been developed. This system has distributed the detection process and magnitude estimation in each field station in order to reduce costs and improve efficiency.

1.- Introduction

Mexico is located near the joint of three tectonic plates. The subduction process is the tectonic feature that has the highest seismic activity and the Cocos Plate is the main source of the activity (fig. 1). Strong earthquakes (M>5) in the Pacific Coast of Guerrero are detected in the city and major earthquakes (M>7) could cause severe damage.

The observed recurrence period for major earthquakes in this part of the Middle America trench, is between 30 and 35 years. Therefore it is possible to limit seismic gaps where M>7 earthquake would occur in a relative short time. The San Marcos and Guerrero gaps have the highest seismic risk in this zone (fig. 1).

Strong earthquakes show hypocenters with focal depths between 15 to 30 km near the coast and the smaller ones have focal depths form 32 to 42 km (Suárez et al, 1991). If the major earthquake expected in the Guerrero gap takes place, the damage in Mexico City would be similar to the one occurred on September 19, 1985, because the seismic waves are enormously amplified at lake bed sites and even at hill zone sites (Ordaz and Singh, 1992). Figure 2 shows the Mexico City area affected during the 1957, the 1978 and the 1985 major earthquakes.

2.- Seismic Alert System Description.

The Seismic Alert System (SAS) was designed in 1989 (Espinosa-Aranda et al. 1989[a]), it has a Seismic Detector System (SDS) installed along the Guerrero Coast; a Communication System (CS), is a digital telecommunication system between the state of Guerrero and Mexico City, where a Central Control System (CCS) broadcasts a signal to trigger automatic devices and processes.

The SDS are 12 digital strong motion field stations (FS), distributed 25 km far one from another each of them is based on microcontroller and microprocessor devices. The sensors are silicon piezoresistive triaxial accelerometers. The sampling frequency is 50 Hz and data is 20 bits wide.

The FS should detect any seismic event for focal distances shorter than 100 Km. This consideration has been examinated to design the seismic trigger algorithm for the SAS. Additionally, we assume as a major seismic risk for the Mexico City area if they are generated from the Guerrero or San Marcos gap.

The FS processor used to detect and estimate the magnitude of an earthquake is a standard commercial IBM PC-XT compatible LAPTOP microcomputer with additional boards. The data is stored in standard 3.5” floppy disks.

The CS is based on one VHF Central Radio Relay Station (RRS) near the Guerrero Coast and three UHF Radio Relay Stations. To improve the reliability of the SAS, the CS has another path with the same features at a different frequency so as to have a redundant system. Additionally every station generates and transmit its own supervision code signals every twelve hours.

The CCS is an IBM PC-AT compatible computer which captures the messages sent from the FS and automatically controls the warning broadcasted by UHF radio in the Valley of Mexico.

An interesting remark of this system is that each FS has the ability to detect the seismic event with the given restrictions by its own. These features reduce the costs considerably and improve computer efficiency, in contrast of other systems that receive by telemetry all the signals at the same time and needs heavy computer process.

3.- The Earthquake Detection Algorithm.

Many seismic event detection techniques have been developed in recent years (Lee and Stewart, 1981; McEvelly and Majer, 12982; Allen R, 1978; Stewart, 1977), most of them handle a Short Term Average/Long Term Average Ratio (STA/LTA). Each FS senses in real time the arrival of the P and S phases of the seismic waves, using the Average Square Input (ASI) as a Characteristic Function (CF) that verifies the signal process analyzing the short term average (STA) of the site acceleration. If the STA/LTA ratio is greater than a given threshold, then the declared event would be accepted. In addition to this first approach, the detection algorithm (Espinosa-Aranda, 1989b) handles a second threshold in order to detect the S phase arrival. We also need to know if a major event is under development and if its magnitude is big enough to warn the Valley of Mexico. The same detection routine is used to estimate the maximum level and rate of variation of the average function integration, in order to estimate the possible magnitude M among the following ranges: $5<M<6$, $6<M<7$, or $M>7$ of the earthquake detected.

To identify seismic events using acceleration records from a FS in the near field (fig. 3 top) it was necessary to define the thresholds levels 1 and 2 and a time window between the S and P phase called Interval Observation (IO), (fig. 3 middle) to ensure that the incoming signal is indeed coming from the distances range expected. Finally, when the event is accepted, the FS reports the maximum value reached by the CF integration function at the 2 (Ts-p) time. (fig. 3 bottom).

The most suitable method was the CF function define as:

$$CF(i) = 1/n \sum_{k=1}^{n} SA(i) \quad ...(1)$$

n number of samples
where SA,

$$SA(i) = \sum_{j=1}^{3} Aj^2(i) \quad ...(2)$$

$Aj^2(i)$ is the i square sample of the j component

After several trials n was fixed to 32, to keep CF as a short time average.

When STA/LTA > Level 1 then the preseismic event (PE) condition is reached.

Once the PE condition is obtained, the algorithm will continue comparing the signal to another threshold (level 2) looking for the S phase. When this condition is satisfied, then the Event Confirmation (EC) is reached. The EC must be detected in the IO time window, if the algorithm reaches the EC, then an earthquake is in process.

4.- Earthquake size criteria.

The magnitude size comes out to be the most difficult task, because of the short time lag available.

The detection algorithm needs the differentiate two warning levels.

a) Trigger only strong motion array in the Valley of Mexico. (5<M<6) (Aguilar and Alcántar, 1991).

b) Trigger strong motion array and automatic devices and processes. (M>6).

On top of every other constrain it should do it in only a few seconds.

By integrating the CF function, the obtained function allows to estimate a proportional value of the energy. Once the 2 (Ts-p) time is reached. The maximum value of the integration functions is obtained, as well as its rate of variation. It is desirable to be able to distinguish also earthquakes with magnitude among the following ranges, 5.0 to 6.0; 6.0 to 7.0 and bigger than 7.0. Efforts have been made in order to accomplish this aim, using the data recorded from the strong motion arrays of the area, a valuable set of seismic accelerograms, gathered in the Guerrero Coast from 1985 to 1990 (Anderson et al. 1987, 1989a, 1989b an 1990) were used to test the detection algorithm and to generate calibration curves to determine the hierarchy of the alert signal.

The Mb magnitude for the P phase was chosen because in some cases the final time of the trigger algorithm 2 (Ts-p) could not reach the highest amplitude of the signal. Unfortunately not all the accelerogram set could be tested.

The test accelerogram needed the P arrival and previous noise and most of them are triggered after the P arrival. This consideration decreased highly our data set, and also it was considered only the minimum focal distance accelerogram for each earthquake. Calibration curves are used to trigger the warning system, they are not used to estimate any magnitude. (fig. 4).

Furthermore, the system has been designed to allow the Digital Signal Processing (DSP) hardware to use an harmonic analysis to estimate the magnitude and to improve the detection accuracy and phase analysis in real time.

5.- Results and Conclusions.

In a period of seven months, the SAS was set fully operational and has been operating for ten months. Currently, the CS is working only with one communication path. Nevertheless, the 97% of successful transmissions during this initial stage, makes the communication system highly reliable.

The most common failures observed during this period are, power failures that have caused spurious triggers and frequency interference due to a variety of causes.

At the beginning the FS was operating with an electric offset in the sensors, which overestimated the original threshold. In spite of this fact, an earthquake was recorded (fig. 5). Modifications to the software were done at time to record some recent earthquakes (April 26, 1992) reported successfully to the CCS.

This system has finished successfully the first stage (installation, tests and calibration). At this point our main concern is to improve the detection accuracy and the magnitude estimation. Besides we would like to take advantage of the information we handle in real time to estimate the localization and some focal parameters with certain digital processes as first arrival polarity and polarization analysis.

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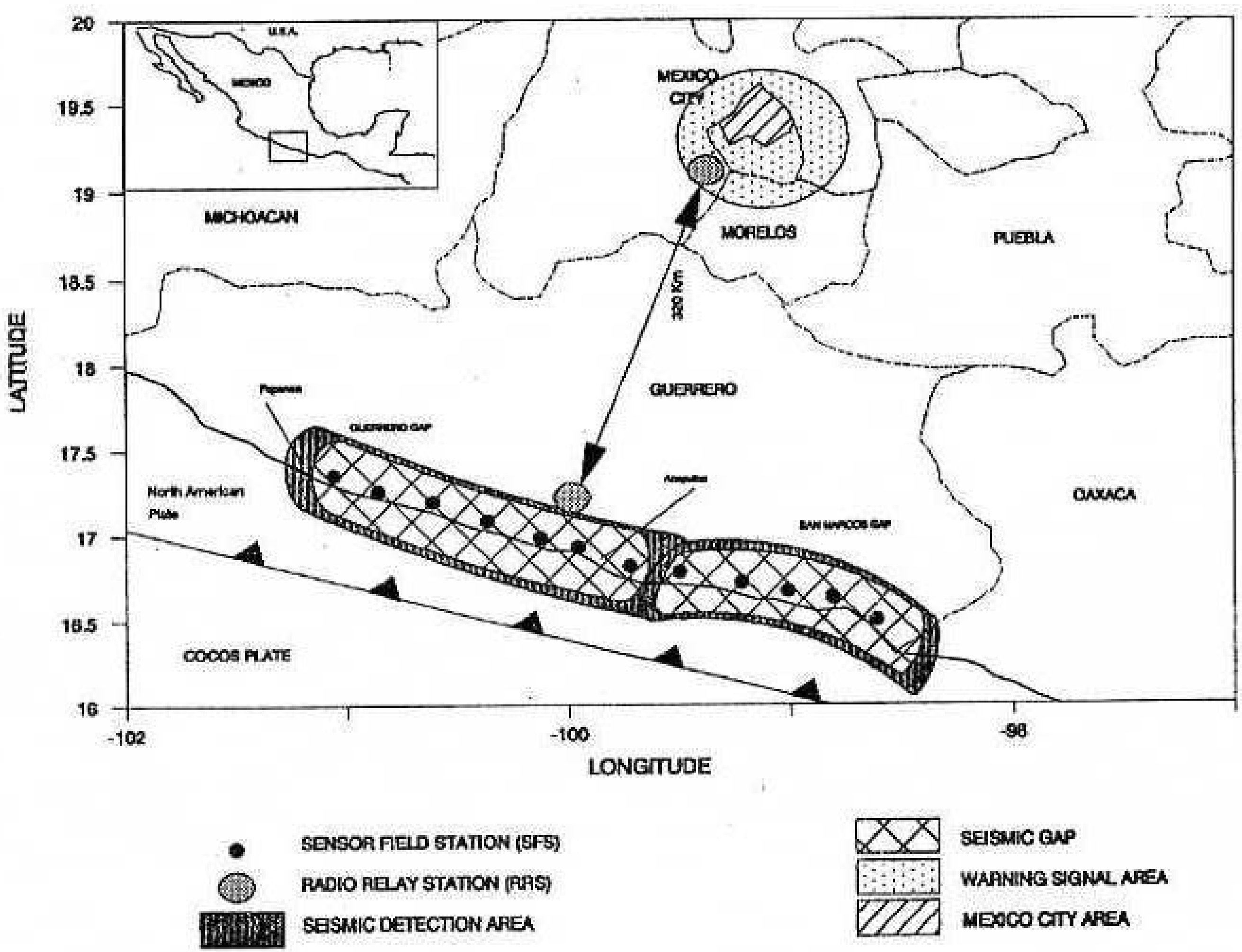

Fig 1. Schematic array of the Seismic Alert System (SAS). The subduction process is the main seismic source of the zone. Guerrero and San Marcos gaps are shown.

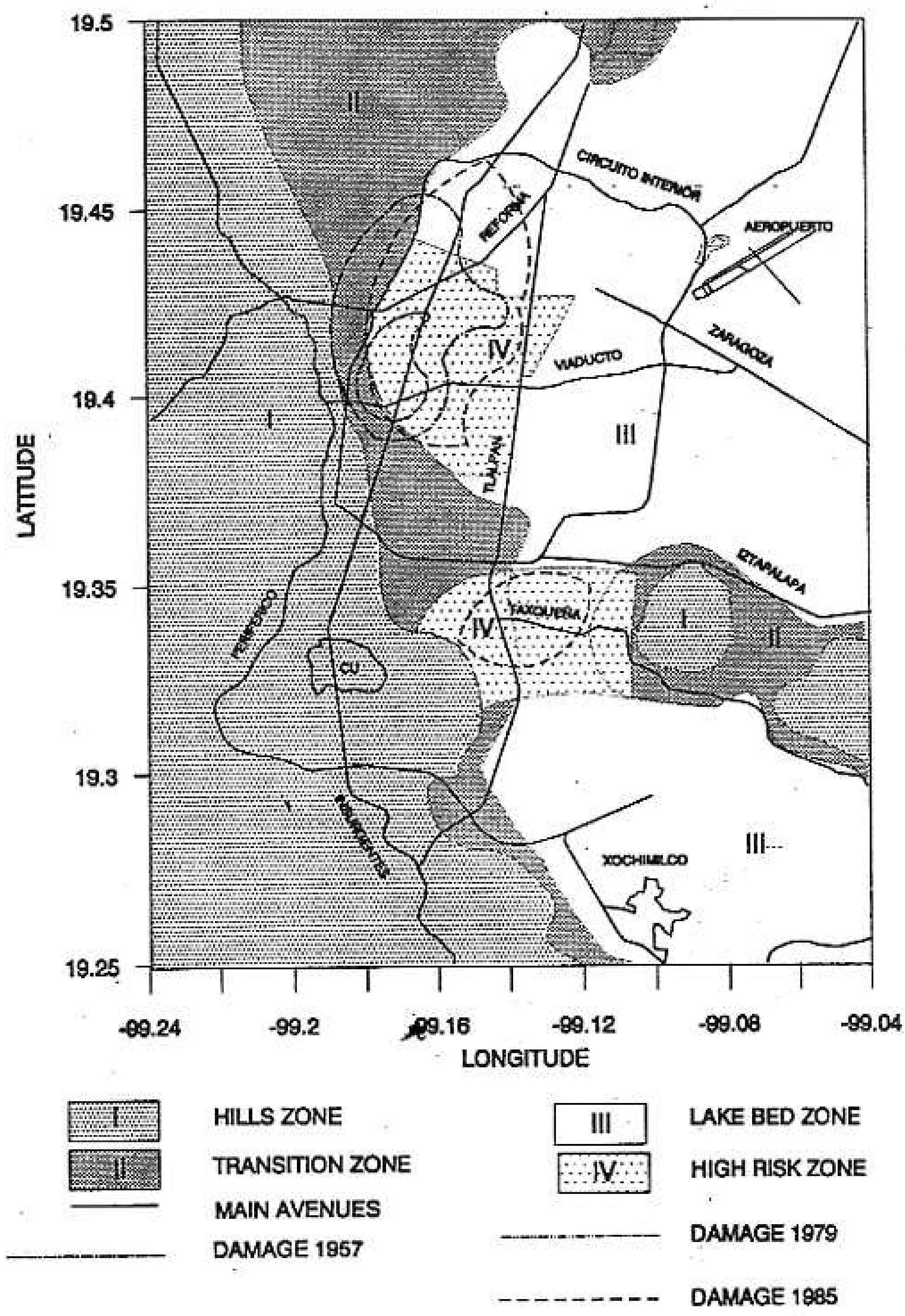

Fig 2. Map of Mexico City, showing boundary among hills, transition and lake bed zones. Damage zones for the 1957, 1979 and 1985 major earthquakes are shown.

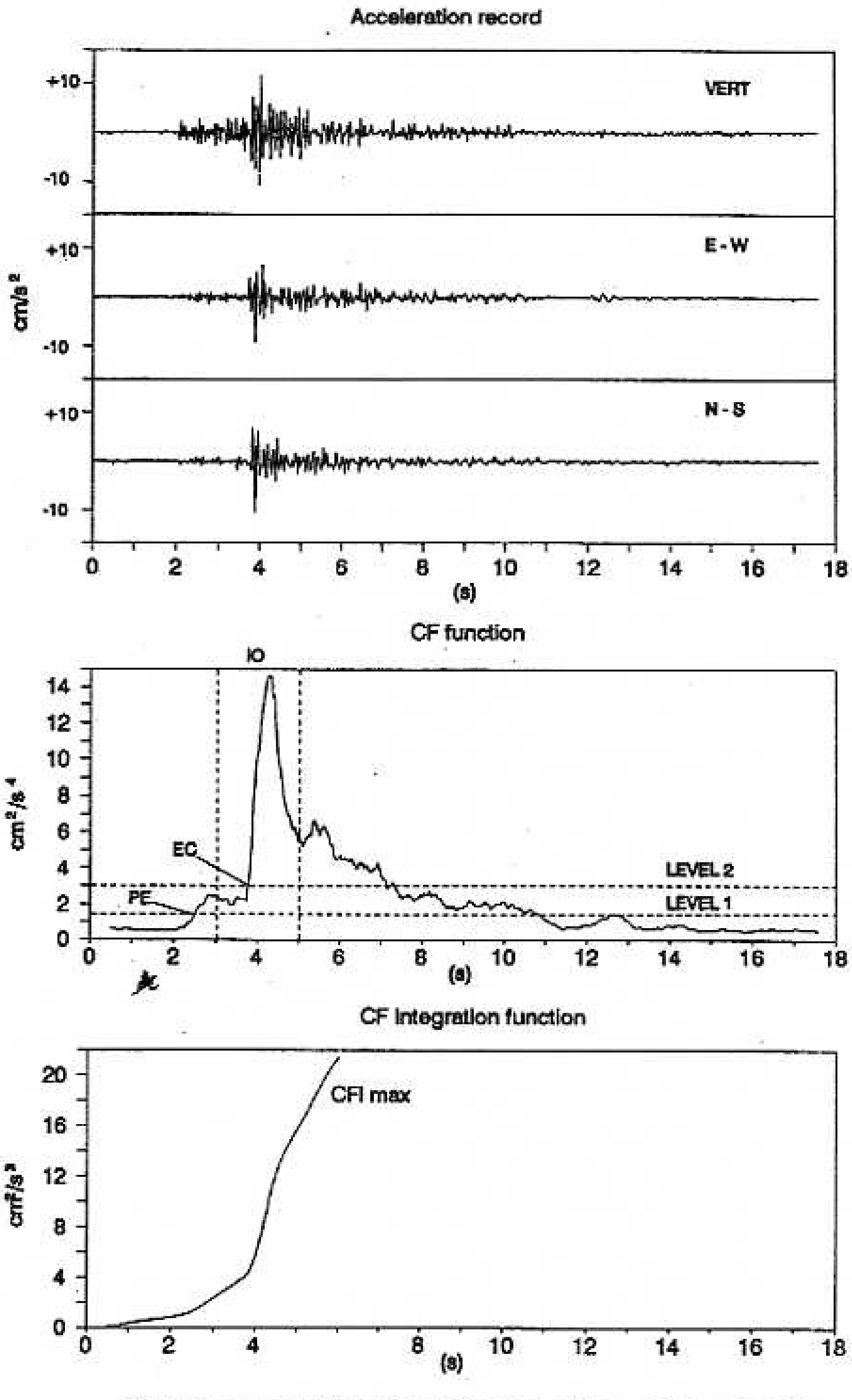

Fig 3. Upper shows the acceleration record for a given earthquake. Middle shows the characteristic function (CF) of the detection algorithm. Preseismic event (PE) and Event Confirmation (EC) time is shown. Bottom shows the integration function of the CF, the last value and its variation rate its sent to the Central Control System (CCS).

SAS MAGNITUDE CALIBRATION CURVES

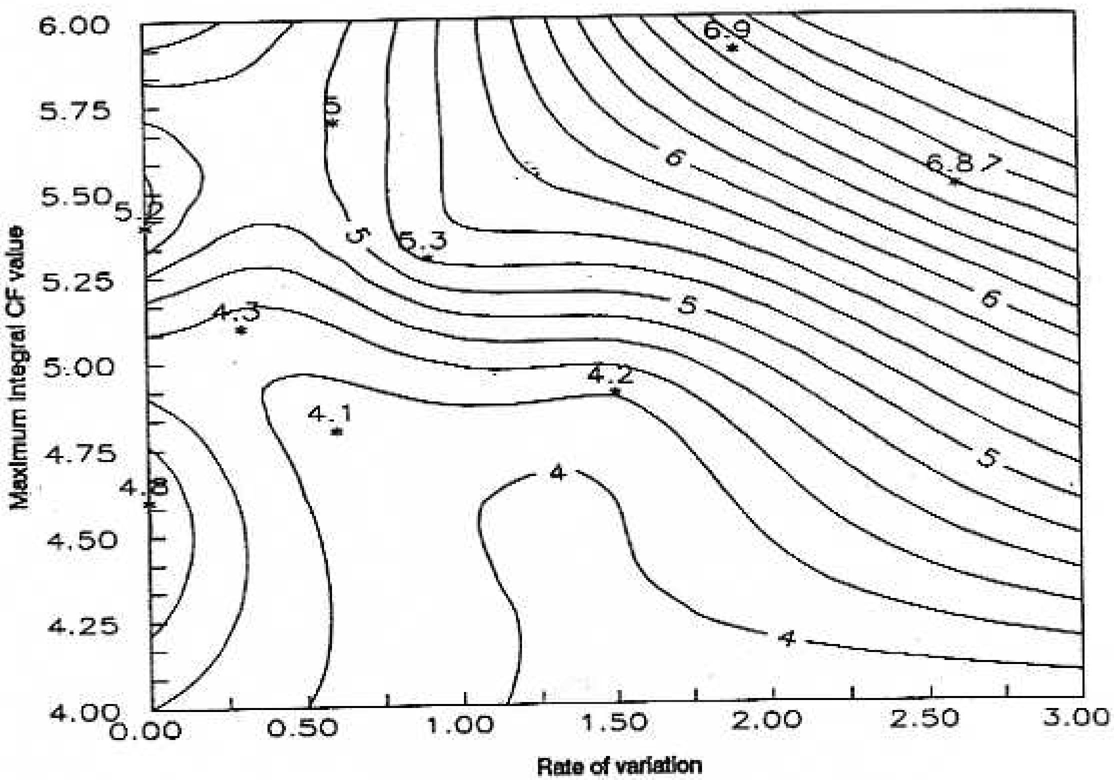

Fig 4. SAS magnitude calibration curves. The Mb magnitude is plotted against Rate of variation and maximum Integral CF value. The area bigger than 5 is the trigger criteria.

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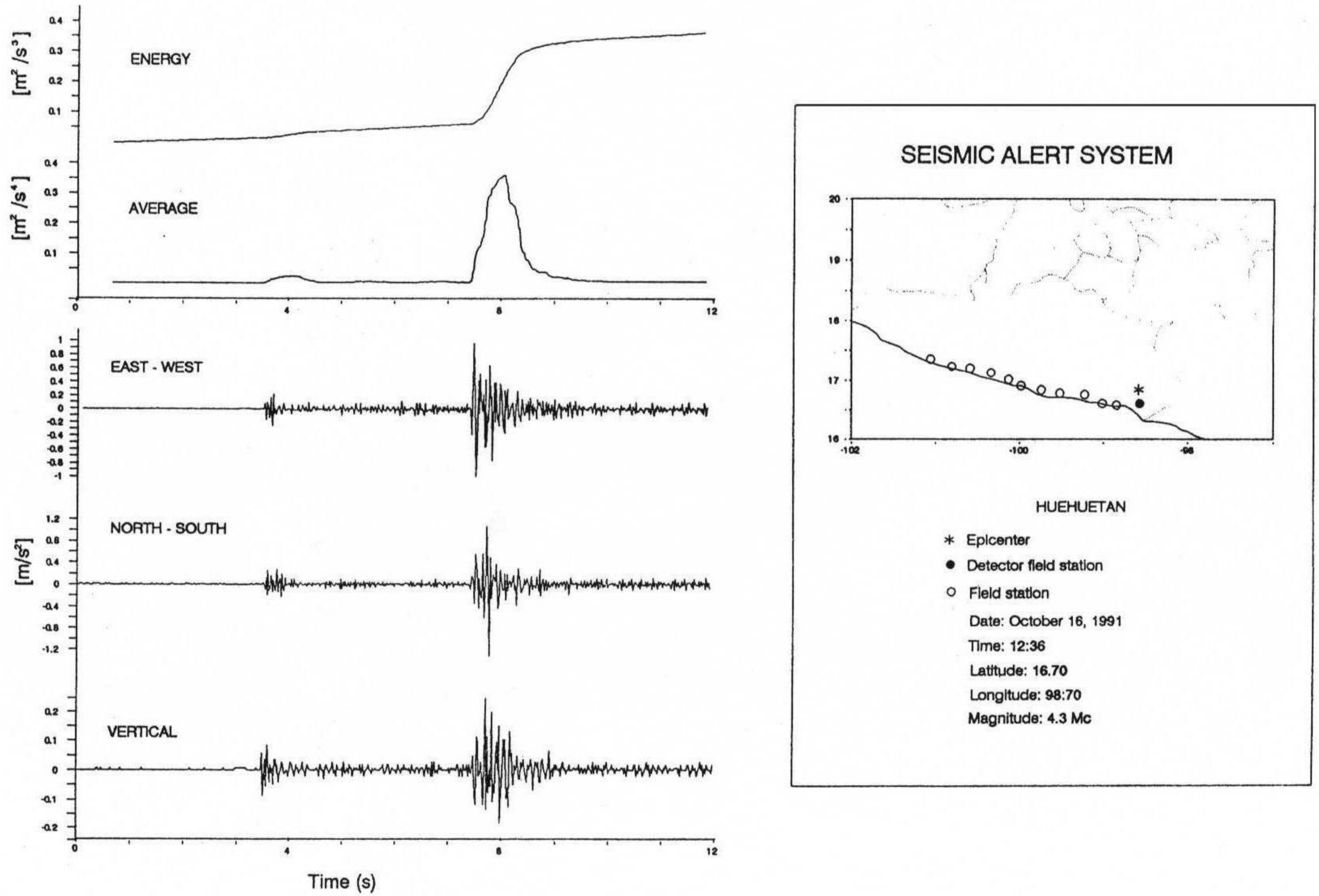

Fig 5. Huehuetán record (October 16th, 1991). First seismic recording of the SAS