AN EVALUATION OF THE MEXICAN STRONG MOTION RADIO TELEMETRY NETWORK AFTER THREE YEARS OF OPERATION

by

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SYNOPSIS

The Seismotelemetric Information System of Mexico (SISMEX) became operational in 1973. Its main purpose is to record ground motion during earthquakes in the Valley of Mexico and neighboring areas. In the last three years, operation, maintenance and modification of sensitivity ranges, as well as improvement of recording techniques, calibration procedures, protection against electrical transients and further software development, have been possible with moderate effort. Advantages of the system over other earthquake recording instrumentation lead to the capability of computing response spectra in a matter of hours after the event.

INTRODUCTION

SISMEX consists of 14 field stations generating five seismometric and 54 ground acceleration signals. These are multiplexed and transmitted over six VHF radio links to a central station where each multiplex is recorded continuously together with time signals and the multiplex from a local station at the main campus of the University of Mexico (fig 1). By means of a playback unit, a set of discriminators, a minicomputer, time code readers, an A/D converter and other peripherals, all processing leading to the computation of response spectra is performed at the central recording station (CRS). Digital tapes are also prepared for processing larger quantities of data at the University computer center. A more detailed description of SISMEX is found in ref 1.

This paper deals with various aspects of the system operation, including an overall evaluation of key operational parameters, long term stability, influence of environmental factors, life expectancy of instruments and a description of calibration procedures. Results for an earthquake of moderate intensity are presented.

OVERALL SYSTEM PERFORMANCE

After the experience gained with the operation of SISMEX some comments are appropriate regarding the instrumentation used. Although problems were encountered, some valuable features of the system as modularity, self-monitoring of equipment condition and flexibility for easy change of operational parameters have lead to an operable system with reasonable maintenance work. Routine daily checking at the central recording site of all subcarrier frequencies allows the detection of incipient problems such as low batteries, degraded transmiter efficiency, etc, so maintenance is programmed to preserve accuracy and reduce station down-time to a minimum. Some environmental factors of traditional concern, such as temperature and aging effects on field equipment, have been minimized, assuring long term stability. For instance, subcarrier center frequencies do not depart more than 0.5 per cent from the original values in the station at the University campus, more than three years after installation.

Study has been directed to heighten immunity to such factors as radio interference, lightning strokes and both intentional and accidental man-made damage. Lessons learned have lead to improved station design, better equipment layout and more effective electrical transient protection. This refining program has been conduced together with routine maintenance, aimed at the ideal of reducing it to battery changes and calibration checks.

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OPERATIONAL CHARACTERISTICS

Data collection

Sensitivity. Because the minimum signal threshold is limited by noise, two steps have been taken in order to increase dynamic range. The first concerns sensitivity. Two levels were originally designed for acceleration signals (± 1.0 g and ± 0.04 g, full scale) with overlap between them. In order to have a better signal to noise ratio for all acceleration magnitudes of practical interest, changes were introduced to produce three gain levels (± 1.0 g, 0.1 g and 0.01 g, full scale) instead of two. This resulted in improved recordings of acceleration of up to 0.01 g, which hardly affect common structures but are widely felt for a minute or more in most of Mexico City during frequent moderate-size earthquakes. The second step refers to the main factors introducing noise in the link. These have been located and reduced through modifications to the original scheme. They have proved to be of value as described subsequently.

Noise rejection. Because the information is handled by frequency modulation, noise content in the recovered signal after demodulation is much less than the individual noise contributions of the conditioning, trasmitting and recording blocks. Theoretical noise-in-input to noise-in-output ratio[2] for ± 125 Hz deviation and maximum intelligence frequency of 25 Hz, as employed in SISMEX, is 35 db. Even poor signal to noise ratios of 20 to 26 db can be tolerable without a significant signal degradation, and typical values, much better than these, are obtained with ease both in the radio links and in the tape recordings.

Radio disturbances. Random radio interference by other users of the crowded VHF band used has posed a difficult problem because of the factors involved. It is possible currently to recover the signals with a S/N ratio of 40 db relative to full scale. Further refinements will tend to increase this figure to 60 db, typical for this class of systems.

Tape speed compensation. It was found that the tape transport speed control as supplied by the manufacturer was not precise enough for the task. Recordings revealed both a definite increase in flutter when transports were exposed to vibration or supports were shaken to simulate an earthquake. Tape speed also changed according to the relative amounts of tape in the supply and take-up reels, as revealed by frequency changes in reproduced tones. As these effects in turn produced severe degradation of signal to noise ratio and limited the attainable time accuracy, a closed-loop tape-synchronization scheme using a pilot tone recorded simultaneously with the seismic information was implement by the CRS staff. This resulted in an overall flutter and speed accuracy better than 0.03 per cent. this value represents approximately a worse-case signal to noise ratio of 40 db which is further improved with the conventional substracting-type flutter-compensation techniques originally devised.

Timing. The time signals from a code generator and the one received from WWV by a diversity receiver are recorded to provide a redundant and accurate event timing. Both epicenter determination and correlation among any desired combination of acceleration signals benefit from this feature.

Calibration. Each individual module of the multiplexing and demodulating equipment is brought to nominal specifications within one per cent, assuring interchangeability for easy maintenance. An overall check-up is made to the measuring chain in the laboratory when equipment is ready for installation. However, once in the field it would be difficult to detect relatively small variations in module characteristics and their influence on overall calibration constants. Again, calibration of field instruments right after earthquakes would be impractical. Fortunately, the system configuration admits a dynamic overall calibration of each acceleration channel. This is attained by injecting a controlled standard signal which lasts about 4 sec and can be digitized at 1 msec intervals.

A complex system function which bears information on both amplitude and phase is computed from digitized laboratory and transmitted standard signals. This function is defined at frequency intervals of about 1/4 Hz up to frequencies beyond the nominal cut-off of the several low-pass filters used in the measuring chain. Accurate timing and this calibration procedure give information about overall behavior which can hardly be obtained from conventional electro-optical strong motion instruments. Additional refinements are still required for the automatic transmission of the calibration sequence several minutes after each earthquake without interference with any aftershocks that might occur.

Data processing

Analog and digital filtering. There are well known advantages of digital over analog filters when strong motion acceleration signals recorded on photographic material by conventional accelerographs are processed. Among the main drawbacks of common analog filters, phase-shifts and amplitude degradation are mentioned[3]. At the SISMEX recording station the former can be controlled by proper selection of filter parameters and both effects can be measured by means of the calibration described, to make the required corrections. There is a clear advantage of analog filtering: if convenient it can be performed before digitization takes place. SISMEX signal recordings can profit from the relative advantages of both analog filtering in the early processing steps and digital filters in later stages.

Digitization. Equipment and associated software are available at CRS for fully automatic digitization at constant time intervals. Here lies one of the significant advantages of SISMEX over an array of photographic type accelerographs for which digitization is at best a heavy and time consuming task. Not only the sampling rate may be varied over a wide range (multiples of 1 msec) but the filtering effects of digitization at unequally spaced points are avoided and, best of all, digitization is completed in minutes even for the longest records at the usual sampling rates of 100 or 200 samples/sec.

Data selection. The combination of a large-screen oscilloscope for quick-display purposes and development of related software at CRS is a valuable feature of the system for it permits rapid assessment of digitized data in order to select that part of the acceleration signals which is to be processed by means of the system minicomputer. Integration and response spectra calculation capabilities are referred to in connection with a specific earthquake in the following paragraphs.

RESULTS

Since the first acceleration station began operating in 1973 only a few low intensity earthquakes have been felt in the area covered by the SISMEX stations.

One significant result was obtained from the Guatemala earthquake of Feb 4, 1976. At a distance of over 1 000 km ground acceleration was recorded in the three most sensitive channels that were working at that time on an experimental basis at the University of Mexico. As shown in fig 2, the maximum acceleration was 1.3 gal in the NS component[4].

The first test of the installation as an integrated system came about with a moderate sized earthquake (M= 6.3) originating at a distance of 320 km, off the Pacific coast on June 7, 1976. Reaction was compared with rehearsed procedures. A few hours after the earthquake, response spectra calculations were complete for the most important acceleration components from 4 stations in the typical soils found in Mexico City and from one in Puebla (first ground acceleration ever recorded in this city). A preliminary report including seismological data, maximum accelerations at those five stations, duration of acceleration peaks greater than 4-gal (near the threshold of sensitivity of the human body at rest), integration of uncorrected accelerations, logarithmic plots of response spectra for zero damping, maximum ordinates of absolute acceleration spectra for 2, 5 and 10 per cent damping and comments on the relationship between these and current design spectra was published two days after the earthquake[5].

CONCLUSIONS

Continuous three years operation has shown that SISMEX is an economically feasible and technically advantageous system that profits from the built-in flexibility regarding module specification, operating mode and field station location, provides an easy access to information revealing condition of remote instrumentation and requires reasonably low maintenance efforts. Optimum performance still needs an additional improvement program which seems warranted in the light of the experience gained.

The collection of strong motion earthquake information by means of SISMEX has significant advantages over other procedures: wider dynamic range, the possibility to combine analog and digital filtering and the ready availability of digital data, which greatly reduces the time required to reach the interpretation stage.

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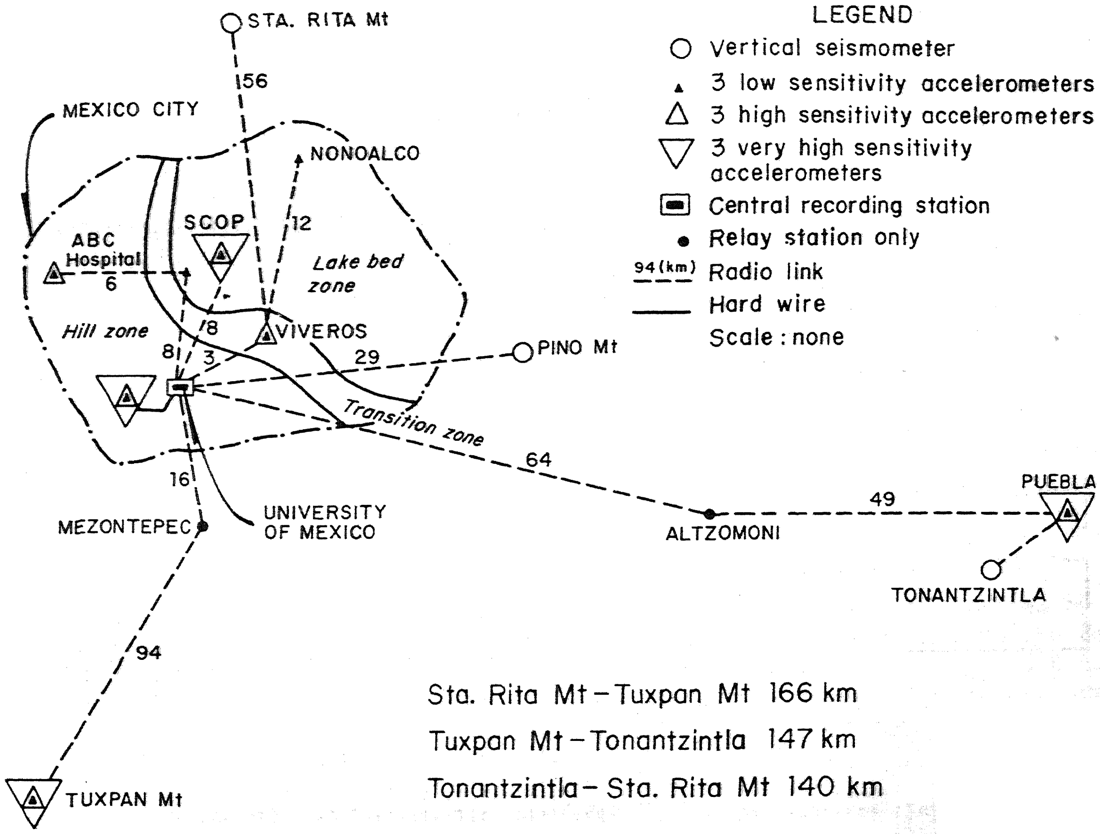

Fig 1. Layout of SISMEX network

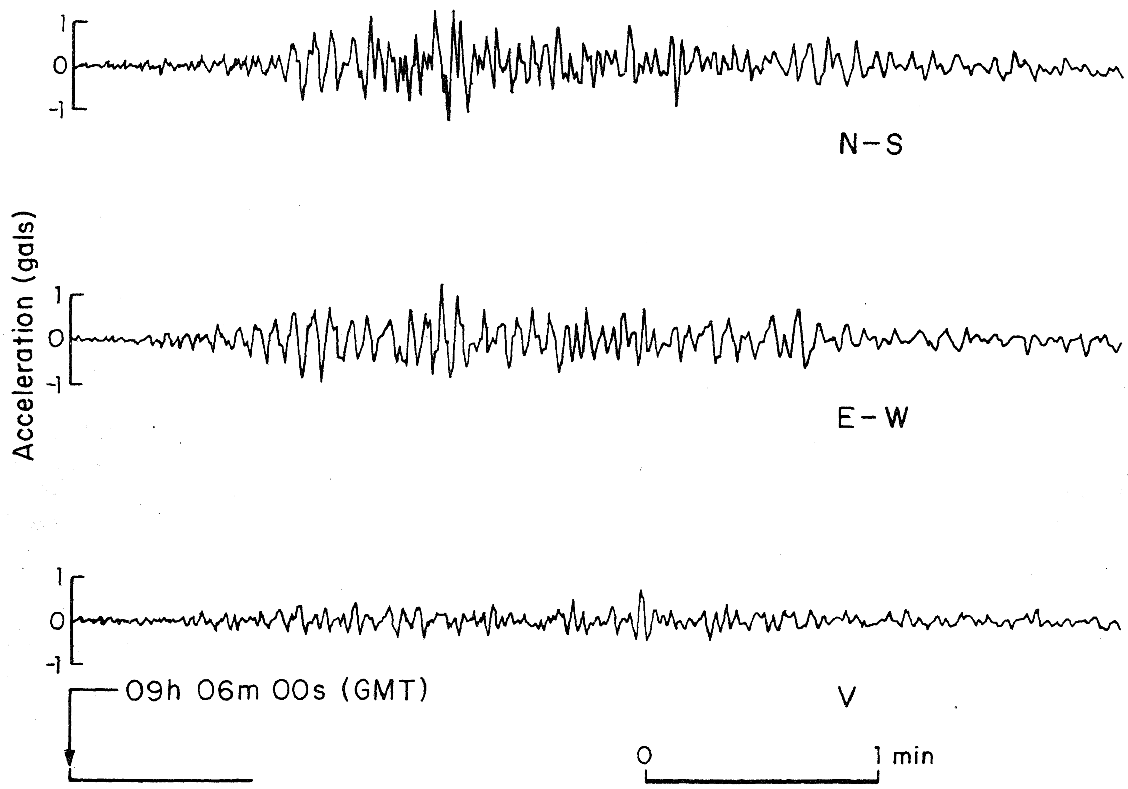

Fig 2. Ground acceleration of the Guatemala earthquake (Feb 4, 1976) recorded by SISMEX at the National University of Mexico, Mexico City

DISCUSSION

M. Steinwachs (Germany)

What type of triggering system do you use in the Mexican Strong Motion Radio Telemetry Network and what is the value of the trigger level.

Author's Closure

Not received.