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SEISMIC ACTIVITY IN THE AGUAMILPA DAM, MEXICO

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ABSTRACT

The first filling of the reservoir in the Aguamilpa Dam started on June 25, 1993 and microseismicity was generated near to the site 30 days later. The activity (Reservoir Induced Seismicity, RIS) was detected by the seismographs installed along the Santiago River and were recorded over 100 low-magnitude events per day (Maza, 1993). To support those observations and to determine the largest seismic activity area, the Gerencia de Ingeniería Experimental y Control of the Comisión Federal de Electricidad (GIEC-CFE) set a seismic network around the reservoir from March to September, 1994. During the period were located 1222 events whose magnitudes were calculated between 0.5 to 3.

The RIS analysis was done using the events that had a magnitude in excess of 2.5 and it was possible to find out the existence of a graben built by El Rosario Viejo fault and the lineament of the Los Picachos and El Colorín hills. Taking into account the geological structures of the zone, it is considered that the El Sauz fault could be potentially the most active fault and the filling produced a stress-state change and reactivated it.

KEYWORDS

Reservoir Induced Seismicity, Aguamilpa Dam, Hydroelectric Central, Seismic Network, Active Fault, seismograph record.

INTRODUCTION

Reservoir Induced Seismicity (RIS) is easier to detect in areas were the seismicity is low because there is an important increase after the first filling of the reservoir and to the close relationship between water level changes and the number of earthquakes. Aguamilpa Dam is an excellent case of that phenomenon.

The Hydroelectric Central Aguamilpa is placed in the State of Nayarit, México (52 km to Tepic City) as is shown in Fig. 1. The dam is one of the earth and rockfill and a concrete slab of 187 meters high and has a capacity of 2575 million cubic meters. According to the Mexican Seismic Chart (Esteva, 1970) is located in Zone 1 (low seismicity).

The variations in seismic behavior around the dam, owing to a rise in microseismicity, indicated the presence of RIS, such affirmation was based upon the studies carried out by the Gerencia de Estudios en Ingeniería Civil de CFE.

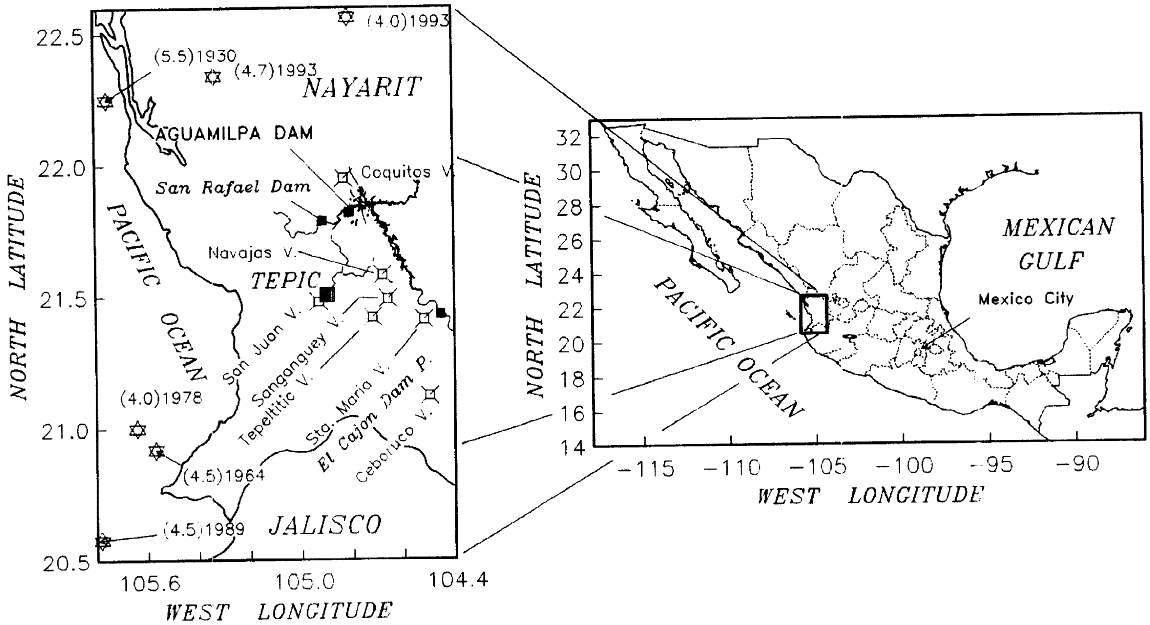

Fig. 1 The Hydroelectric Central of Aguamilpa

A seismological network was installed in 1987 and because of the low seismicity of the region just a few small local events were detected. The first filling of the reservoir started on June 25, 1993 and RIS happened 30 days later. The seismological stations began to record small shocks whose magnitudes were less than 1, but later the rate of occurrence and the magnitude rose (Maza, 1993) (Fig. 2). Because of CFE is interested in knowing the seismic behavior in an area near to the Central and its possible effect on the dam, it was considered necessary to increase the number of stations around the reservoir. The purpose is to have better hypocentral parameters to do some seismological studies that will permit to interpret the source and the failure mechanism. That is why the Gerencia de Ingeniería Experimental y Control (GIEC) set a local network close to the damsite.

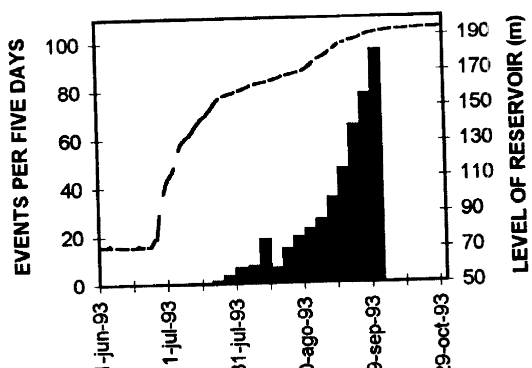

Fig. 2 Events recorded after first filling

GEOLOGY

The Hydroelectric Central of Aguamilpa is placed on the limits of the physiographic region formed by the Sierra Madre Occidental and the Transmexican Volcanic Belt, in a complex area where the Rivera, North American and Pacific plates converge. According to the geology in the Aguamilpa site there are three main stratigraphic units (P.H. Aguamilpa, 1988): 1). The inferior sequence (Aguamilpa Formation) that is integrated by Ignimbrites, Dacites (Pseudostratified) and well-cemented Riodacites. This formation exists in almost all the project. 2). The intermediate sequence is composed by Ignimbrites of the Colorines Formation which shows continuos pseudostratification, and this is the only difference with the previous one. 3). The

Picachos Formation is constituted by intrusive dikes which are different in age and composition. Those structures penetrate into the Ignimbrites of the inferior and intermediate sequences. The dikes have a varied composition ranging from Porfiritic Andesites to Diabases Monzonites. Some of the dikes have 500 m length and parallel direction to the longitudinal dam axis, and therefore they work as a natural barrier against underseepage.

The geological structures of the region like faults and graben systems have a NNW-SSE direction due to the presence of a volcanic range, being the El Ceboruco and El Coquito the volcanoes with the most recent eruptions (Venegas *et al.*, 1994; Ferrari *et al.*, 1994a, c) . There are some others structures oriented NE-SW that conform a rift (Palma, 1994) and important faults in the same direction and NW or SE dip. Upstream are located the El Sauz and El Rosario faults, that are oriented NW-SE and NE-SW respectively, making a graben system. They are classified as active ones, because there are evidence of recent displacements, there is not deposition of plants or other organic materials within joints and fractures, and besides the rocks do not show weathering effects (Uribe, 1994a, b).

The fault and fracture systems, indicate that El Rosario Viejo fault is the oldest because the existence of segmentation produced by the displacements of some fractures in NE-SW direction, which propagate towards the El Sauz fault without sectioning, so this fault could be the youngest in the region. Finally, it can be mentioned that there are signs of magma chambers that generate thermal water (e.g. Agua Caliente Stream). On that site was installed a seismological station.

INSTRUMENTATION

For monitoring RIS seven seismological stations were installed, four portable seismographs MEQ-800 (with vertical seismometer of 1 s period) and three component digital accelerographs (IDS-3602). One station was placed on the dam and the others were "free field", Fig. 3 shows the site locations and table 1 their geographical coordinates.

The seismological array operated from March to September, 1994 and then was retired; nevertheless there is an Accelerograph Network that is still working (Roldán *et al.*, 1993).

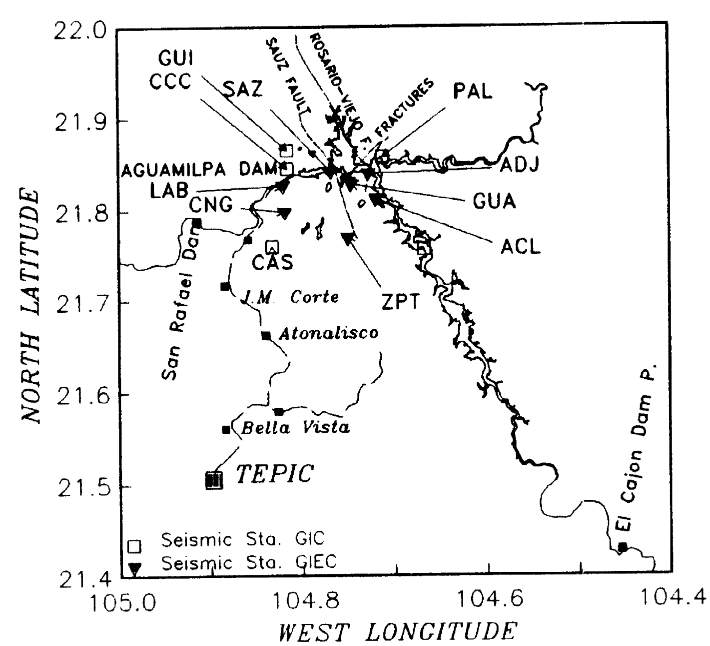

Fig. 3 Temporal Seismological Network

Table 1. Temporal Aguamilpa Seismic Network

STATION (CODE)	COORDINATES LAT N	LONG W	ELEVATION (m)
Arroyo Agua Caliente (ACL)	21.812	104.716	200
Las Adjuntas (ADJ)	21.839	104.728	200
El Sauz (SAZ)	21.841	104.768	200
Las Guacheras (GUA)	21.828	104.747	200
Laboratorio Instrumentación (LAB)	21.826	104.820	120
Ejido El Zapote (ZPT)	21.770	104.736	600
La Ciénega (CNG)	21.798	104.818	520

ANALYSIS

As it was mentioned induced seismicity phenomenon began 30 days later and it was possible to locate 1222 events with the temporal network, Fig. 4 presents the relation between number of events and the Reservoir level. The number of them that were processed versus depth and magnitude are shown in Fig. 5.

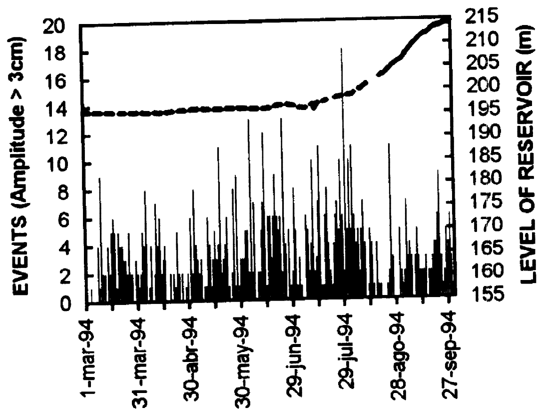

Fig. 4 Events recorded and Reservoir level

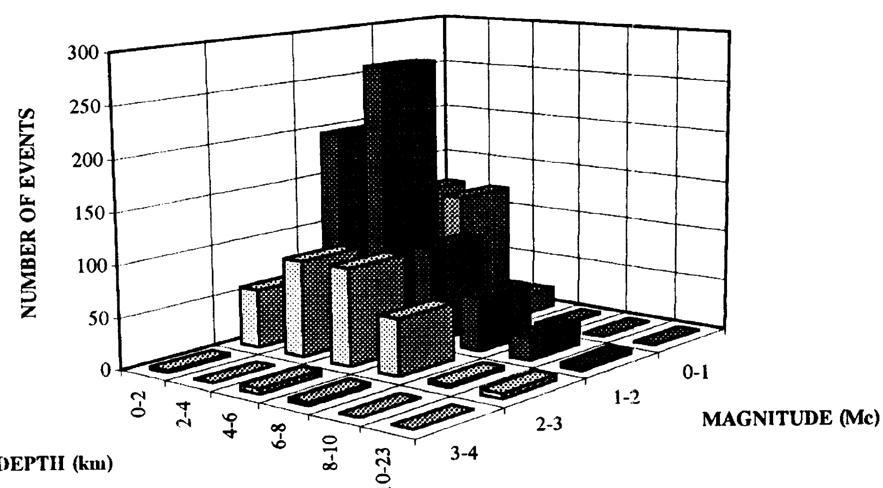

Fig. 5 Events processed

The majority of the events had a depth between 1 to 4 km, and were associated to magnitudes from 1 to 3. The events whose magnitude were in excess of 3 were located with a depth between 4 and 6 km.

The hypocentral parameters were computed using the HYPO71PC program (Lee and Valdés, 1985) and the velocity model assigned is presented in table 2.

The coda magnitude was calculated by:

$$Mc = -0.87 + 2Log_{10}(T) + 0.0035(D) \quad (1)$$

where: T is the signal duration in seconds and D is the epicentral distance in km.

Table 2. Velocity Model (Uribe, 1994)

VELOCITY (km/s)	DEPTH (km)
3.50	0.00
5.00	5.00
6.10	20.00
6.05	25.00
7.60	35.00

The events selected for the analysis had a magnitude bigger than 2.5 and are shown in Fig. 6, almost all had more than 8 seismic phases (P and S).

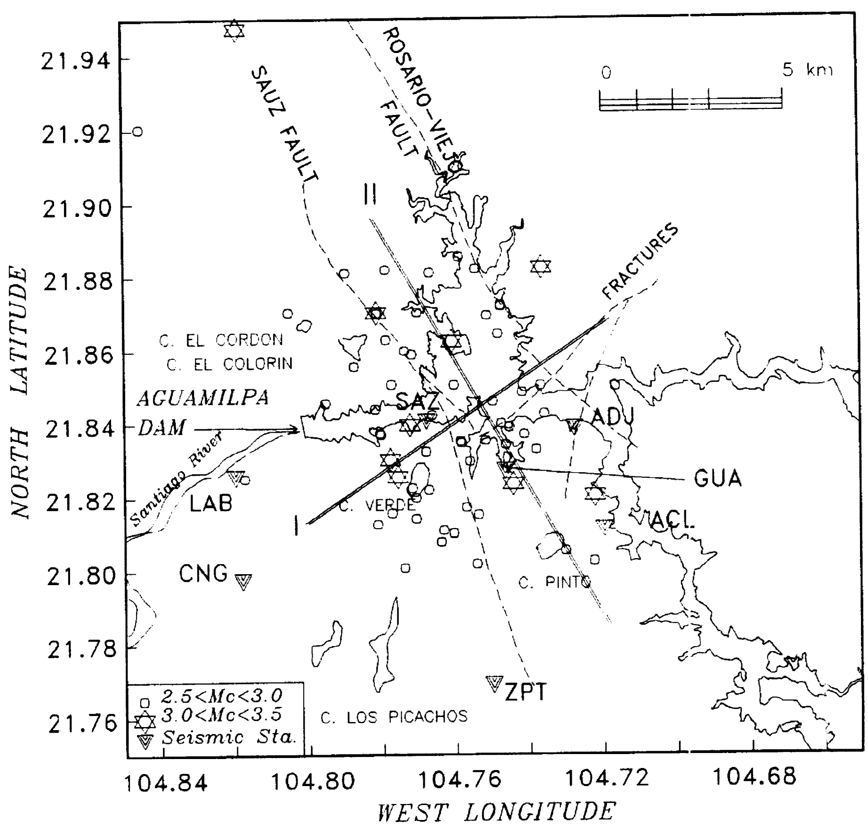

Fig. 6 Epicentral location of the events analyzed

It can be concluded that the mean seismicity was concentrated in 3 areas:

- The first one is located southern Cerro Verde and slightly through El Sauz fault. This zone was considered active because the occurrence of 3 events whose magnitudes were from 3 to 3.5.
- The region between La Guachera and the largest dike. The area was activated after the water level of the reservoir started to rise (from July to September, 1994). Here was located the biggest earthquake (M=3.4) during the monitoring period.

- The last one is ubicated northern the Hydroelectric Central and is bounded by the El Sauz and El Rosario Viejo faults, which constitute a graben. The events took place in a short period of time (August 8 to 19) when the water level began to rise.

In order to analyze the focal distributions two seismic profiles arrangements were made (Fig. 7) according to the epicentral location. The first one shows a shallow seismicity and is limited just for the reservoir area. It was expected that one border were El Sauz fault, but the activity spread out 2 km western. The second permitted to observe that the major earthquakes (M = 3 - 3.5) were generated close to the dam and whose depths were not greater than 7 km. The hypocenter locations were within a band of 3 km wide and 45° dip approximately.

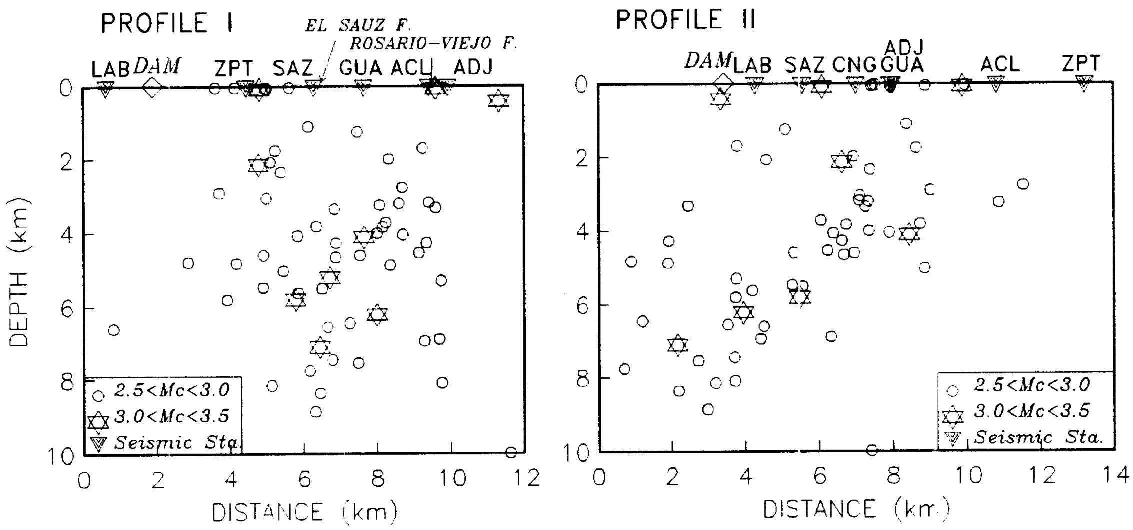

Fig. 7 Seismic profiles

Earthquakes have not occurred with magnitude greater than 5 in the studied region, the nearest took place 100 km away. However, some events (M>4) had been located to distances less than 50 km through NW Aguamilpa. Such activity could be related to hydrothermal phenomena because there are some volcanoes in NW-SE direction being the most importants El Ceboruco, Tepetiltic, Sangangüey, Las Navajas and Los Picachos. During the monitoring period on June 14, 1994 an earthquake (M = 3.3) occurred and whose epicenter was located 10 km away from the damsite, but that event is not related to the RIS in the area.

Considering that the El Sauz fault might generate an earthquake, the next expressions were used to estimate the magnitude:

$$Mo = ULHD \tag{2}$$

$$Mw = 2/3 \mathrm{Log}_{10} Mo - 10.7 \tag{3}$$

where Mo is the Seismic Moment, U the Ignimbrite rock Shear Module, L the El Sauz fault length, H the estimated fault depth, D the fault displacement and Mw the Seismic Moment Magnitude.

The fault length was calculated as 15 km, U is 1.823×10^{10} dynes/cm^2 , H was considered 5 km like the focal depth average. If the fault had suddenly 1 cm displacement, thus Mo = 1.37×10^{22} dyne/cm^2, that it means an earthquake of magnitude Mw = 4.8.

CONCLUSIONS

The region where the Aguamilpa Dam is located is considered one of the low seismicity, and the filling of the reservoir triggered induced seismicity. Even though the seismological network covered a wide area, the epicentral distribution was concentrated on a small zone near to the damsite, and after the four events of August (3 < M < 3.5) the seismicity dropped.

It was established a very close relationship between the water level changes and the number of seismic events, having a frequency from 4 to 7 days of activation, it was also observed an increase in the magnitude values.

According to the events studied the area behaves as a graben bounded by the El Rosario Viejo fault and the lineament of Los Picachos, Cerro Verde, El Colorín and El Cordón hills.

It is important to mention that there are presence of thermal water owing to the recent volcanism and might be contributing to the microseismic activity. That was the case of the Agua Caliente Stream Earthquake (M = 3.4), in which the depth was 1 km.

Related to the geological and seismological information, it might not be expected an earthquake with a magnitude in excess of 5 in the Aguamilpa region.

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