Copyright © 1996 Elsevier Science Ltd
Paper No. 2132. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

RESULTS OF THE MEXICO CITY EARLY WARNING SYSTEM

ESPINOSA-ARANDA J. M., A. JIMENEZ, G. IBARROLA, F.ALCANTAR, A. AGUILAR, M. INOSTROZA, S. MALDONADO

Centro de Instrumentacion y Registro Sismico, A.C.
Anaxagoras #814, CP 03020 , Mexico, D.F.
E-mail: maranda@servidor.unam.mx
Home page: http://www.unam.mx/cires

ABSTRACT

The Seismic Alert System (SAS) is a public seismic early warning system for Mexico City, which has been operating as an experimental evaluation project since August 1991. The system gives an advantage of 60 sec. on average for earthquakes generated in the Guerrero Gap. It was designed to broadcast a general alert above the threshold M≥6, and a limited alert for earthquakes with M≥5. The occurrence of the M7.3 earthquake of September 14, 1995 was a test that checked the whole system. The early warning was activated and a signal was broadcasted 72 seconds prior to the arrival of the strong ground motion. The public policy and behavioral response aspects of the exercise of September 14, 1995 are presented.

KEYWORDS

Early Warning Systems, earthquakes, Seismic Alert System, public response.

INTRODUCTION

Most of the large earthquakes which are likely to cause damage in Mexico City have their source in the subduction zone of the Pacific coast, where the Cocos plate has generated 42 earthquakes with magnitudes greater than 7 this century (Esteva, 1988). The Cocos plate lies approximately 320 kilometers from Mexico City and has been quiescent for more than 30 years. The M8.1 Michoacan earthquake of September 19, 1985 killed about 10,000 people, left tens of thousands homeless, collapsed over 200 buildings, and seriously damaged hundreds of others. Scientists believe that an earthquake, similar in size to the one in 1985, has a very high probability of occurrence before the year 2000 (Anderson *et al.* 1994). There is concern among scientists and government officials about earthquakes due to the high vulnerability of Mexico City because of soil conditions (Ordaz and Singh.,1992) and structural characteristics of buildings.

The *Centro de Instrumentacion y Registro Sismico* (CIRES) developed the *Seismic Alert System* (SAS). The purpose of this public earthquake early warning system is to communicate an emergency message to government officials, operators of vital services, and the population that a large earthquake has just occurred on the Guerrero Gap and is going to strike Mexico City. The system has provided as much as 30 to 72 seconds average advance warning before damaging ground motion generated by the earthquake reaches Mexico City (Espinosa Aranda *et al.,* 1995).

The development of the early warning system began in 1989 and was completed in August, 1991. It is now operating as an experimental project and CIRES is responsible for its enhancement, operation and maintenance. The SAS is the only public earthquake early warning system that is operating to date. Real time earthquake early warning systems, are utilized in other nations but are either not shared with public agencies, as in Japan (Nakamura and Saito, 1982) and Taiwan (Chung *et al.,* 1995; Lee *et al.,* 1995), or have been pilot tested on a temporary and experimental basis only, as in the United States (Bakun *et al.,*1994). Other systems like the Caltech-USGS Broadcast of Earthquakes (CUBE) send information to the emergency operation centers in California about epicenter, magnitude and a map of the areas most likely to have sustained damage but this information is sent after the shock and is not shared with the public.

THE MEXICO CITY EARLY WARNING SYSTEM

The Seismic Alert System consists of four parts: the Seismic Detection System, a Dual Telecommunications System, a Central Control System and a Radio Warning System for users. The seismic detector system consists of 12 digital strong motion field stations located along a 300 km stretch of the Guerrero coast, arranged 25 kilometers apart. Each field station includes a microcomputer that continually processes local seismic activity which occurs within a 100 km radial coverage area around each station. An algorithm locally detects and estimates magnitude of an incoming earthquake within 10 seconds of its initiation (Espinosa Aranda, 1989a, b). If it is estimated as $M>6$ or $M\geq 5$ a warning message is sent. At least two stations must confirm the occurrence of the earthquake before the public alert signal is automatically sent from CIRES to the public.

The Dual Telecommunications System consists of a VHF central radio relay station, located near Acapulco, and three UHF radio relay stations located between the Guerrero coast and Mexico City. Two seconds are required for information sent by one of the field stations on the Guerrero coast to reach Mexico City; this data is sent digitally coded.

The Central Control System continually receive information on the operational status of the field stations and communication relay stations, as well as the actual detection of an earthquake in progress. Information received from the stations is processed automatically to determine magnitude and is used in the decision to issue a public alert (Jimenez, *et al.*, 1993). In order to generate an early warning signal, two thresholds are defined: M_1 ($M\geq 6$) and M_2 ($6>M\geq 5$). When an earthquake of M_1 or M_2 is determined, a warning message is automatically broadcast by the UHF radio transmitter located in the central control station.

The Radio Warning System for users disseminates the seismic early audio warnings via commercial radio stations and audio alerting mechanisms to residents of Mexico City, public schools, government agencies with emergency response functions, key utilities, public transit agencies and some industries (Jimenez, *et al.*, 1993). Public and private entities are equipped with specially designed radio receivers to obtain the SAS alert. In each place there is a person in charge of the SAS receivers. His duties are to check the status of the receiver and coordinate all the activities of disaster prevention as exercises and drills of evacuation.

Coverage of the Radio Warning System

The radio receivers installed in the commercial AM/FM radio stations, schools of the Federal Department of Public Education *Secretaria de Educacion Publica,* the public housing complex of *El Rosario* and the Mexico City commuter rail organization METRO are very important due to their social impact.

There are 24 radio receivers installed in the commercial AM/FM radio stations. Since September 1995, there are special audio control designed by CIRES to switch over the standard audio program from the radio stations to a 60 sec. prerecorded message of early warning. This message consists of a clearly identifiable special tone and the statement "seismic alert, seismic alert" in Spanish "*alerta sismica, alerta sismica*", this statement is automatically broadcast without the intervention of human operators. Earlier in some stations a cassette had to be inserted into the broadcast equipment in order to play the alert message with the eventual loss of valuable time. The warning message does not contain technical information, specific guidance of protective actions, description of potential dangers or severity of the earthquake.

Since 1992, the *Secretaria de Educacion Publica* has been an active participant in the development of the system. Although only twenty-seven schools have been equipped with SAS radio receivers, the education authorities have designated personnel that among other duties permanently monitor the radio station during the classroom hours and manually turn on a siren in case of an early warning. The estimated scope of people covered with this method in the schools is 1.9 million students and teaching personnel.

El Rosario is a densely populated public housing project inhabited by 200,000 inhabitants. The area is characterized by low rise multi-unit apartment buildings constructed between 1960 and 1970 and surrounded by open areas and recreational facilities. *El Rosario* has a public audio warning system connected to the SAS. At this location, a system of power loudspeakers are installed in a tower. The early warning is broadcast as a clearly audible signal. It is estimated that the number of inhabitants receiving the warning signal are 10,000.

The Mexico City commuter rail organization METRO uses the early warning system to command trains to travel at reduced speed and stop at the next station upon receipt of a warning notification. It is estimated that 600,000 persons are traveling during rush hours.

There are a number radio receivers in the Civil Protection Agency, the Public Works Department *Secretaria General de Obras*, the Central Command of the Mexican army *Estado Mayor del Ejercito*, some public buildings in Mexico City, the public electric utility CFE, universities, the offices of the XXXVI District of the Mexican army, the Central Agency for Disaster Prevention *CENAPRED,* the police department of the state of Mexico and the law enforcement task force *Procuraduria General de Justicia.*

Public Education and Response to SAS

The government of Mexico City developed and disseminated a brochure to 2 million households as an effort to raise the awareness of the SAS and provide instructions on how to best respond to an alert. This brochure describes how the early warning system works and gives instructions about how the residents should respond to an alert as well as advice on preparedness activities, actions to take during an earthquake and after the shaking has ceased. The brochure recommends: turning off utilities, opening emergency doors, helping children, older persons and others requiring assistance, and either taking cover inside or evacuating the building using predesignated routes. Also a radio spot has been transmitted repeatedly along the day in the radio stations. This announcement begins with a short introduction of the official tone of the seismic alert and then continues giving instructions selected from the brochure.

The Department of Public Education in cooperation with the civil protection authorities have trained students to respond to the early warning and these response procedures are reinforced through regular exercises. Evacuation drills at schools are held at least monthly and in some cases with greater frequency. Earthquake education and response readiness is carried out in all the schools of Mexico City, not only in those with SAS radio receivers. Today, the SAS has become a part of the Mexico City public school program of earthquake hazard reduction.

Residents of *El Rosario* created a community organization after the 1985 earthquake disaster which conducted training in appropriate response actions including those which should be taken in a warning situation.

EXERCISES AND TESTING OF THE SYSTEM

To assure that all SAS radio receivers installed are functioning properly and the personnel is aware of the early warning, CIRES and the Mexico City government have designed a periodic general test. Two warning signals are transmitted from the Central Control Station one of supervision and the other of general alert. All receivers are checked for a proper issued warning and a correct procedural response of personnel. All users are equipped with receivers which respond to the alert signal from SAS. When the warning is received in the radio receiver a switch output is closed. Usually, the user has connected a secondary device that issues the warning signal which is commonly a siren.

Five general tests have been carried out, one in December 1994, and the other four in 1995, starting in April 1995 at intervals of two months. Table 1 shows the results of these tests. The line corresponding to the radio receivers that are out of service, correspond to radios delivered to users, who are still reluctant to install and operate them. The high percentage of radio receivers that failed in the test of October 6 1995, corresponds to a group that is connected by a relay station with the city of Toluca near Mexico City, where a radio interference caused the radio relay station failure. In the next test of December 1995 the encoded radio message was repeated two times giving a significant improvement of efficiency.

Table 1. Summary of performance of radios on SAS testing

	test Dic 13	test Apr 7 9	test Aug 4	test Oct 6 9	test Dic 1 9
Operated	80.6	77.5	85.7	77.5	89.8
Failed	1.0	5.1	3.0	12.2	0.0
Out of servic	18.3	17.3	11.2	10.2	10.2

This general testing of the early warning is not transmitted to the public that listens the radio stations. Special emphasis in checking the AM/FM stations is done. A private engineering company carries out the supervision of the test to do a technical audit of the system.

THE SEPTEMBER 14, 1995 EARTHQUAKE

At 8:04 a.m. on Thursday September 14, 1995, a magnitude 7.3 earthquake occurred in the Mexican state of Guerrero, approximately 95 miles east of Acapulco and 190 miles south of Mexico City (Anderson *et al.*, 1995). The casualties were 5 dead and several dozen injured. Damage, though considerable in coastal towns near the epicenter, was minor in Mexico City. Figure 1 illustrates the SAS performance. The map shows the location of the six stations who detected the event, the first one was Marquelia (station 11) at 8:04:42, the second was Huehuetan (station 12) at 8:04:46, which confirmed the event, followed by El Carrizo (station 10), Las Vigas (station 9), El Cortez (station 8) and San Pedro (station 7). Below that, in real time, the figure shows the earthquake records gathered by the field stations, the time when the alert was on, and at the bottom one of the earthquake accelerograms registered in Mexico City.

This earthquake is quite significant in that it served as a test that checked the whole system. The early warning was activated and a signal was broadcasted 72 seconds prior to the arrival of the strong ground motion. The report on performance of the radio receivers and public response was elaborated by means of a

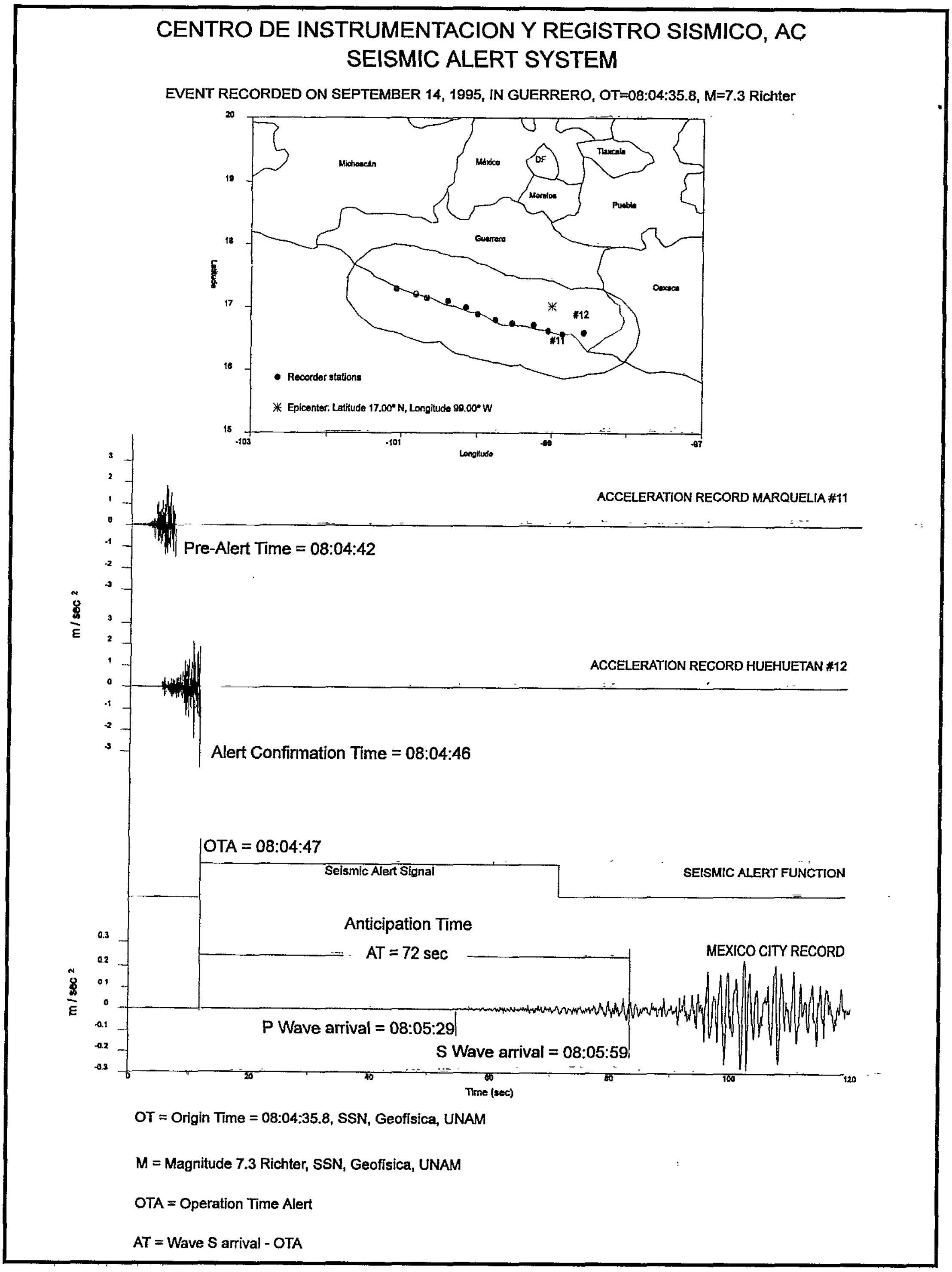

Figure 1. Time Diagram of the Seismic Alert System response on September 14, 1995.

survey carried out with the users in charge of the SAS receivers. Table 2 shows the performance of the 98 radio receivers. Only twelve radios were not installed by the users and are labeled OUT OF SERVICE.

Table 2. Radio receivers activated on the earthquake M7.3 of September 14, 1995.

ORGANIZATION	OPERATE	OUT OF SERVI	TOTAL
Public schools	28		28
AM/FM Radio stations	22	2	24
Government agencies	20	10	30
Universities	3		3
Subway METRO	2		2
Private industries	2		2
El Rosario	1		1
CIRES technical personnel	6		6
Public buildings	2		2
TOTAL	86	12	98

Public Response on September 14, 1995

This earthquake occurred during the peak hour on a working day, at that time many people were already at or were going to their normal place of employment. Normally the METRO and public transportation is crowded. Standard hours of people to arrive at their jobs is at 8:00 or 9:00 A.M. All secondary schools of children 12-15 years of age and Universities had already started classes at 7:00. Elementary schools of children 5-12 years of age start at 8:00.

The early warning system triggered alarms in 28 Mexico City public schools equipped with SAS receivers. The maintenance personnel in almost all schools with no SAS receivers were monitoring the radio stations and triggered the alarm manually. This resulted in almost all the public schools being warned. The ensuing evacuations, according to education officials, were orderly and well coordinated.

The audio warning system in *El Rosario* functioned without problem at 8:04 on September 14, providing residents of the community time to evacuate their apartments. Residents indicated that they were frightened when the signal sounded but responded by turning off gas and lights and evacuating their buildings according to established procedures and with the assistance of residents assigned to direct people to the pre-designated evacuation routes and outdoor assembly locations. There were no reports of panic behavior such as running, shoving, or other actions associated with extreme fear and flight reactions.

The Central Control of the METRO received the warning signal and had enough time to stop the trains in the stations, where they opened the doors. Evaluation of the response of people to the early warning broadcasted in the radio stations is difficult. Although there are reports from people who were listening the radio, and heard the warning, and took some action, there are no reliable statistics. The Civil Disaster Management office, Public Works Department, and emergency services alerted their personnel. The police also were alerted and started a general inspection in the city to locate damages.

DISCUSSION

Part of the successful dissemination and activation of the SAS receivers in Mexico City on September 14, 1995 has been due to the tests which have permitted to maintain a periodic supervision of the radio receivers, assuring that the system was completely functional and offering opportunities for improvements in its operation. Also, the public education, training and drills have permitted an adequate response of part of the public. The best response was from the public schools with a population of children with ages from 5 to 15 years of age, which have the highest level of training and experience.

The system had a cost of $1.2 million dollars for development and installation and $200,000 per year for maintenance. The facts that most major earthquakes which are likely to cause damage in the capital are from the Guerrero coast, the people reached by the early warning in schools and METRO if an earthquake strikes on rush hours is about of 2.5 million persons and 4 million listening radio stations make the Seismic Alert System a low investment with high benefit return social value for the Mexico City population.

As it currently operates, the SAS is relatively simple technically with the need to enhance the instrumentation. Limited in its sensor and warning coverage, it provides warning only for events along the Guerrero coast to the people of Mexico City. Earthquakes with other sources could strike Mexico City without warning as it happened in the M7.5 Colima earthquake of October 9, 1995 and M6.5 Chiapas earthquake of October 20, 1995.

More than 100 applications of institutions and private organizations for new installations of SAS radio receivers have been submitted. Unfortunately the current economic situation in Mexico today is still not favorable for expansion of the early warning system. This demand implies the future expansion of the SAS Radio Warning System for users and CIRES technical infrastructure.

Today the applications to schools, public buildings and its limited deployment in the industry at present has not generated controversy. As further deployment of the system proceeds, the system will be more complex and difficult to maintain with a limited budget. There will be greater social and economic consequences as critical processes and functions are unnecessarily curtailed or disrupted in a false alert or malfunction.

Finally, the problem of warning in an scenario of an earthquake striking at night, where the coverage is low, still remains. It requires the implementation of a low cost dissemination channel that can be activated even if the device is turned off.

CONCLUSION

Although establishing a warning effectiveness factor or measure is somewhat ambiguous, the experience of September 14 demonstrated that the combination of adequate public education, training, drills and a properly issued warning can have high social consequences in case of an earthquake disaster. Residents of seismically vulnerable regions can be expected to respond to a brief warning in a controlled, rational and adaptive manner as was demonstrated by the performance of students in the Mexico City public schools.

ACKNOWLEDGMENTS

We thank Paul Flores from Earthquake Engineering who provided invaluable comments associated with the development of this paper and W. H. K. Lee for their helpful and valuable comments on the manuscript. The Public Works Department of Mexico City, *Secretaría General de Obras* del *Gobierno del Distrito Federal* has been sponsoring the Seismic Alert System since the beginning of the project.

REFERENCES.

Anderson J., Quaas R., Singh S. K., Espinosa-Aranda J. M. , Jimenez A.; Lermo J., Cuenca J., Sanchez S. F., Meli R., Ordaz M., Alcocer S., Lopez B., Alcantara L., Mena E., Javier C. (1995). The Copala, Guerrero, Mexico Earthquake of September 14, 1995 (M_W=7.4): A Preliminary Report, *Seismological Research Letters*, **66**, No. 6, November-December, pp. 11-19.

Anderson J., Brune J., Prince J., R. Quaas, Singh S. K., Almora D., Bodin P., Onate M., Vasquez J. R., Velasco J. M., (1994). Guerrero, Mexico Accelerograph Array: Summary of Data: 1988, *Geofisica Internacional*, **33**, pp. 341-371.

Bakun W.H., Fischer F.G., Jensen E.G., VanSchaack, (1994). Early warning system for Aftershocks. *Bull. Seism. Soc. Am.* , **84**, No.2, pp. 359-365.

Chung J. K., Lee W. H. K. and Shin T. C., (1995b).A Prototype Earthquake Warning System in Taiwan: Operation and Results. IUGG, IASPEI XXI General Assembly, Abstract Week A, pp. A406.

Espinosa-Aranda J. M., Frontana B., Maldonado S., Legaria G., Medina M., Uribe A. (1989a). Sistema de Control para el disparo de una alarma sismica. Memorias del XV Congreso Nacional de Ingenieria Civil. Mexico.

Espinosa-Aranda J. M., Uribe a:, Ibarrola G., Toledo V., Rebollar C. (1989b). Evaluacion de un algoritmo para detectar sismos de subduccion. Memorias de los VIII y VII Congreso Nacional de Ingenieria Sismica e Ingenieria Estructural. Guerrero, Mexico.

Espinosa-Aranda J. M., A. Jimenez; G. Ibarrola, F. Alcantar, A. Aguilar, M. Inostroza, S. Maldonado. (1995). Mexico City Seismic Alert System, *Seismological Research Letters*, **66**, No. 6, November-December, pp. 42-53.

Esteva, L. (1988).The Mexico Earthquake of September 19, 1985--Consequences, Lessons, and Impact on Research and Practice, *Earthquake Spectra* , **4**, Number 3.

Jimenez A., Espinosa J.M., Alcantar F., Garcia. J., (1993). Analisis de confiabilidad del Sistema de Alerta Sismica, X Congreso Nacional de Ingenieria Sismica, Puerto Vallarta, Jal, Mexico, pp. 629-634.

Lee W. H. K., Shin T. C. and Teng T. L., (1995).Design and Implementation of Earthquake Warning Warning Systems in Taiwan. IUGG, XXI General Assembly, Abstract Week A, pp. A406.

Nakamura and Saito. (1982). Desarrollo Del Sistema de Pronta Deteccion y Alarma Del Sismo. Ferrocarriles Nacionales, Instituto de Tecnologia Ferroviaria: VI Simposio Sobre Ingenieria Sismica De Japon, Architectural Institute of Japan, Japan Society of Mechanical Engineers, the Japanese Society of Soil Mechanics and Foundation Engineering, Seismological Society of Japan.

Ordaz M. and Singh S. K. (1992) Source Spectra and Spectral Attenuation of Seismic Waves from Mexican Earthquakes, and Evidence of Amplification in the Hill Zone of Mexico City. *Bull. Seism. Soc. Am.* , **82**.