Chapter 4
The Mexican Seismic Alert System (SASMEX): Its Alert Signals, Broadcast Results and Performance During the M7.4 Punta Maldonado Earthquake of March 20th, 2012

A. Cuéllar, J. M. Espinosa-Aranda, G. Suárez, G. Ibarrola, A. Uribe, F.H. Rodríguez, R. Islas, G. M. Rodríguez, A. García and B. Frontana

Abstract The Mexican Seismic Alert System (SASMEX) compromises the Seismic Alert System of Mexico City (SAS), in continuous operation since 1991, and the Seismic Alert System of Oaxaca City (SASO) that started its services in 2003. The SAS generates automatic broadcasts of Public and Preventive Alert Signals to the cities of Mexico, Toluca, Acapulco and Chilpancingo, and SASO by now only to Oaxaca City. Historically in Mexico City, due to their great distance to the coast of Guerrero, the SAS has issued its Alert Signals with an opportunity average of 60 s. In Oaxaca City the SASO gives 30 s time opportunity, if the earthquake detected is occurring in the Oaxaca coast region, or less time, if the seismic event hits near this town. The paper reviews both systems, its performance characteristics and its recent test by the Ometepec M 7.4 earthquake of March 20, 2012.

4.1 Introduction

The Seismic Alert System of Mexico City (SAS) generates automatic broadcast of Public and Preventive Alert Signals to the cities of Mexico, Toluca, Acapulco and Chilpancingo, and the Seismic Alert System of Oaxaca City (SASO) by now only to Oaxaca City. Two types of SASMEX Seismic Alert Signals ranges were determined in accordance with each local Civil Protection Authorities: Public Alert if they

A. Cuéllar (✉) • J. M. Espinosa-Aranda • G. Ibarrola • A. Uribe • R. Islas • A. García
Centro de Instrumentación y Registro Sísmico, A. C., Anaxágoras 814 Narvarte,
03020 México, D. F., México
e-mail: acuellarmtz@yahoo.com.mx

F. H. Rodríguez • G. M. Rodríguez • B. Frontana
Facultad de Ingeniería, Universidad Nacional Autónoma de México,
México, D. F., México

A. Cuéllar • G. Suárez
Instituto de Geofísica, Universidad Nacional Autónoma de México,
México, D. F., México

F. Wenzel and J. Zschau (eds.) *Early Warning for Geological Disasters,*
Advanced Technologies in Earth Sciences, DOI: 10.1007/978-3-642-12233-0_4,

expect strong earthquake effects and Preventive Alert Signal, for moderated ones. SAS originally had 12 field sensor stations covering partial segment of the Guerrero coast, nowadays covers additionally Michoacan, Jalisco Colima and Guerrero coast completely with 36 field sensor stations supported by the Mexico City Government; the SASO has 37 field sensor stations operating in the coast, central and north of the Oaxaca, covering their seismic danger territory. Since 1993, the SAS is pioneer in the automatic public alerts broadcast services, thanks to the support of the *Asociación de Radiodifusores del Valle de México, A.C.* (ARVM). Historically in Mexico City, due to their great distance to the coast of Guerrero, the SAS has issued its Alert Signals with an opportunity average of 60 s. In Oaxaca City the SASO gives 30 s time opportunity, if the earthquake detected is occurring in the Oaxaca coast region, or less time, if the seismic event hits near this town. Also the SASO has been supported since its implementation for local commercial radio stations. To this day the SAS and SASO have generated respectively 14 and 20 Public Alert Signals, also 59 and 13 Preventive Alerts of more than 2200 earthquakes detected by their sensing field stations. Additionally the federal government is promoting to increase the observation capacity of the seismic danger in Mexico City and the other cities located in seismic regions, to detect and warn any strong seismic effect.

To reach better efficiency in the seismic warning delivery, the Government of the Federal District through the Authority of the Historical Center in 2008, to innovate the SAS, installing VHF radio transmitters, similar to the communication technology like the National Weather Radio (NWR) and Specific Area Message Encoding (SAME) called NWR-SAME, following the code standards of the National Oceanographic and Atmospheric Administration (NOAA) and the Emergency Alert Systems (EAS) of United States; adding a new code (SARMEX) with the capabilities like fast response (2 s or less) to emit the earthquake early warning signal in order to enhance the effectiveness in the Seismic Alert Signals required. This technology also will be implemented in the SASO, and recently the federal authorities have decided to support the coverage with NWR-SAME-SARMEX receivers in other populated cities or urban areas located in seismic regions of Mexico.

On March 20, 2012, during the occurrence of earthquake M 7.4 Ometepec Gro., close to Punta Maldonado, the SASMEX warned Public Alert in the cities of Acapulco and Chilpancingo, Gro., and Oaxaca, Oax., and warned Preventive Alert in the metropolitan area of the valley of Mexico. The time of opportunity was between 80 and 40 s, due to the distance between 175 and 360 km from epicenter to cities where the SASMEX broadcasted their public earthquake early warnings.

After experiencing the serious seismic disaster generated by the "Caleta de Campos" M8.1 Michoacán earthquake in 1985, Mexico City Authorities have been promoting since 1989 the design and evolution of *Sistema de Alerta Sísmica* (*SAS*), with the aim to mitigate possible future earthquake damage produced by such as the latent "Guerrero Gap" seismic danger (Espinosa-Aranda et al. 1992).

The original *SAS* idea was developed by *Centro de Instrumentación y Registro Sísmico* (CIRES) Civil Association. This technological resource started its experimental operation in August 1991 and has been available and evaluated as a public service since 1993. To date it is applied and evaluated in more than 80 elementary schools, both private and public, located in urban regions prone to seismic risk and where early warning of seismic alert signals from *SAS* has been useful, as well as in the Mexico City subway rail transport (METRO). Recently has started the installation of more than 40,000 NWR-SAME-SARMEX receivers for elementary public schools of Mexico City.

SAS disseminates public seismic alert in the valleys of Mexico and Toluca, this one located about 50 km NW of Mexico City. In addition, it also alerts on a contract basis to more than 280 miscellaneous institutions comprising schools, public buildings and emergency organizations. The implementation of *SAS* in the Mexico Valley has made possible to anticipate the arrival of the effects of S-waves with an average of 60 s, time enough to allow execution of safety of automatic system procedures for the protection of equipment or systems susceptible to undergo damage, such as power plants, computer systems and telecommunication networks (Kanamori 2003). On May 14, 1993, after *SAS* identified an earthquake M6.0 and anticipated with 65 s the imminent arrival of its effect in Mexico City, the local authorities decided to disclose early warning notices publicly. The alert signal broadcast was possible thanks to the support from most of the commercial radio and television networks grouped in the *Asociación de Radiodifusores del Valle de Mexico* (ARVM), Civil Association, which agreed to contribute as a social service for their audience since August 1993. *SAS*, has high availability and reliability of their four basic sub-systems: Seismic Detection, Communication, Warning Dissemination and Central Control and Recording, to guarantee the effective earthquake alert public service (Espinosa-Aranda et al. 1995).

On September 14, 1995 at 8:04 AM in Mexico City, having elapsed almost ten years after the tragic earthquake of 1985 (Espinosa-Aranda et al. 1995), *SAS* anticipated with 72 s the arrival of the effect of an M 7.3 earthquake occurred near the town of Copala, Guerrero, This earthquake proved the adequacy of the processes of response and evacuation of schools, where the *SAS* early warnings were received, since the population performed these activities successfully (Goltz and Flores 1997).

On June 15th 1999, a damaging M6.7 earthquake induced the Department of Civil Protection of Oaxaca to request CIRES the design, construction and installation of the *Sistema de Alerta Sísmica de Oaxaca* (*SASO*). A better time-efficiency criteria to define the seismic range of the *SASO* warnings emerged in a technological evolution from the original algorithm used by *SAS*, designed back in 1989 (Espinosa-Aranda et al. 1992), to fulfill the requirements demanded by this application.

Thanks to the Oaxaca Authorities initiative, the Mexico City Mayor, with the participation of the Mexican Secretariat of the Interior, it has been agreed a *SASO* and *SAS* function integration to constitute them as a single entity, the so-called *Sistema de Alerta Sísmica Mexicano* (*SASMEX*). And recently has been decided to increase as necessary the number of seismic sensors to provide an effective warning of impending regional seismic risk disseminating notices of seismic alert in vulnerable cities (Fig. 4.1). With the service rendered by EA*SAS* systems in each sensible region, it will be possible to prevent in advance the seismic effects on the site as well as define the most suitable alert warning for each particular risk condition, and to review these factors systematically (Espinosa-Aranda et al. 2009).

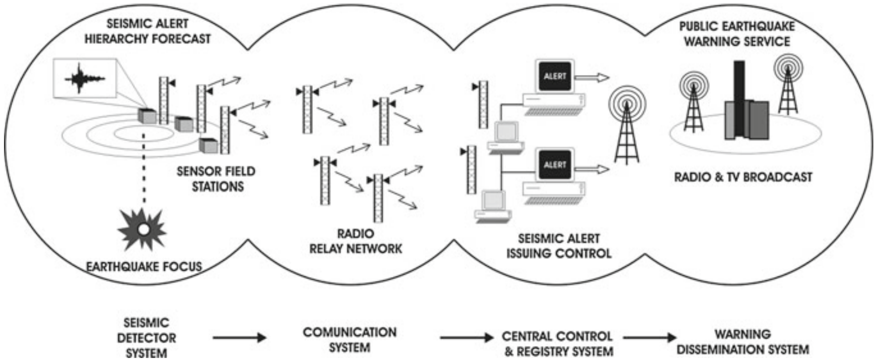

Fig. 4.1 The Mexican Seismic Alert System

In 2007, to support the activities of Civil Protection of the coastal state of Guerrero, Mexico City Authorities authorized the installation of Alternate Emitters for the warning issued by the *SAS* (EA*SAS*) in the cities of Acapulco and Chilpancingo. The EA*SAS* of Guerrero provide public automatic alert services controlling the transmissions of the local commercial broadcasting stations covering the demand of private seismic alert services offered to 102 institutional users.

In order to improve the efficiency in the dissemination of the warning provided by *SAS* initially in schools, recently *La Autoridad del Centro Histórico* in Mexico City sponsored the installation of three dedicated VHF radio transmitters, thus benefiting by the use of commercially available low-cost receivers carrying the Public Alert^{TM} logo, that meet technical standards of NOAA Weather Radio (NWR) Specific Area Message Encoding (SAME) protocols and the Emergency Alert System (EAS) event codes, such as those in use to warn against diverse natural hazards in the USA. The Mexico City application require the NOAA-SAME-EAS protocols, an enhancement in order to include a new code to operate earthquake early warning signals, without delay, omitting the normal two tones previous to signal advise (Espinosa-Aranda et al. 2009).

The Consumer Electronics Association Standards of United States (CEA), approved the Mexican Risks Advisory System (SARMEX) standard that uses all characteristics of the NWR-SAME protocols in March 2011, but enhances the response time when the Earthquake Early Warning codes are emitted, additionally, the Mexican earthquake early warning sound is included to distinguish it from others messages.

4.2 SASMEX Achievements

The SASMEX part for the Mexico City (called SAS) has been regarded as the first system in the world for earthquake early warning that disseminates its notices to the public (Lee and Espinosa-Aranda 1998). The Prevention Time is close to 60 s. This is because the major seismic effects threatening the Valley of Mexico are originated at the coastal region of the Pacific Ocean at a distance of at least 320 km and since their strongest components travel at 4 km per second, taking 80 s to arrive, whereas notices broadcasted by radio from the epicenter area can be transmitted instantaneously anticipating the seismic effects.

The SASMEX forecast begins calculating parameters measured in the Field Stations, FS, when an earthquake is detected, SASMEX in the Mexican Pacific Coast from Colima to Oaxaca, uses the acceleration data of the vertical, longitudinal and transversal components to calculate the Acceleration Quadratic Integration and the rate of this integration, both measured during the 2*(S-P) lapse, that is, the first P wave arrives until the S wave begins. In north and center of Oaxaca it uses the dominant period, measured in the vertical component during the first three seconds after de P wave begins; in case of the S-P is less than 3 s, then the FS uses two additional parameters: the Maximum Acceleration and the Acceleration Quadratic Integration, from the vertical component too (Espinosa-Aranda et al. 2010).

The parameters are sent automatically to determine the alert range, this forecast is used to define the seismic warning range of the impending occurrence of a dangerous earthquake detected by the first two FS (Espinosa-Aranda and Rodriguez 2003). The first FS message defines the warning range, either strong or moderate, and with the second one, triggers the Type of Warning process respectively as "Public Alert" or "Preventive Alert". However the range of Public and Preventive in Oaxaca, Chilpancingo and Acapulco is less than Mexico City, in order to be more sensible due to minor distance from these cities to the danger seismic area in contrast with Mexico City. The Prevention Time is defined as the time elapsed between the beginning of the warning signal and the beginning of the S phase, related to the region where it is intended to mitigate the risk (Espinosa-Aranda et al. 2009).

SASMEX for Mexico City (SAS) since its experimental operational stage in 1991, *SAS* has detected more than 2300 seismic events with magnitudes from M3.0 to M 7.4 and it has emitted 14 earthquakes warnings as "Public Alerts" and 59 as "Preventive Alerts (Table 4.1). The *SAS* performance showed in the Table 4.1 is accounted by the number of FS's that registered each warned earthquake (# SENS. OP.), the Forecast (MAGNITUDE), the Type of Warning emitted (ALERT RANGE) and Prevention Time. The DISTANCE in Table 4.1 is measured from the epicenter to the first FS which detected the earthquake.

SASMEX for Oaxaca (called *SASO)* constitutes a technological development evolved from *SAS*; *SASO* has 36 FS and 11 radio relay stations to link its coastal, central, and northern included isthmus regions (Fig. 4.2). Since its commissioning, *SASO* has issued 20 Public Alert and 13 Preventive Alert warnings from the detection and analysis of more than 230 sensed earthquakes (Table 4.2 similar to Table 4.1).

From April 2012, *SASMEX* identifies the strong earthquakes along the coast of the State of Guerrero, Michoacán, Jalisco and Colima with a linear layout of 36 of SAS and 11 of SASO FS spaced approximately every 25 km to be able to perform an efficient survey because many seismic foci of this region occur at similar depths (Fig. 4.2).

Table 4.1 SAS Performance of earthquake early warnings since 1991–2012

#	Region	NACIONAL SEISMIC SERVICE (SSN), UNAM				SAS FORECAST RESULT		
		Local date-time	Latitude	Longitude	Depth (km)	Sens. Op.	Alert range	Prevention time (s)
72	Oaxaca	02/04/2012 12:36	16.27	−98.47	10	6	Preventive	80
71	Oaxaca	20/03/2012 12:03	16.42	−498.36	15	7	Preventive	80
70	Guerrero	10/12/2011 19:48	17.84	−99.98	58	10	Preventive	16
69	Guerrero Coast	18/06/2011 17:55	16.92	−99.60	26	5	Preventive	
68	Guerrero Coast	05/05/2011 08:24	16.61	−98.91	11	6	Public	65
67	Guerrero Coast	25/05/2010 18:36	17.11	−101.2	15	8	Preventive	63
66	Guerrero Coast	27/04/2009 16:46	16.90	−99.58	7	4	Preventive	57
65	Guerrero	27/03/2009 02:48	17.35	−100.82	30	7	Preventive	58
64	Guerrero	11/11/2008 05:02	16.62	−100.8	15	4	Preventive	
63	Guerrero	06/11/2007 00:35	17.08	−100.14	9	9	Public	68
62	Guerrero	28/04/2007 08:56	16.94	−99.82	9	6	Preventive	
61	Guerrero	13/04/2007 03:43	17.27	−100.27	51	8	Preventive	56
60	Guerrero	13/04/2007 00:42	17.09	−100.44	41	6	Public	58
59	Guerrero	31/03/2007 00:18	17.00	−99.79	34	5	Preventive	
58	Guerrero	18/09/2005 06:25	17.05	−100.02	8	3	Preventive	
57	Guerrero Coast	09/01/2003 20:08	16.97	−100.3	30	7	Preventive	58
56	Guerrero	27/09/2002 02:04	17.16	−100.59	37	4	Preventive	58
55	Guerrero Coast	25/09/2002 13:14	16.86	−100.12	5	4	Preventive	57
C	Guerrero Coast	18/04/2002 12:02	16.42	−101.1	15	0	Fail	
54	Guerrero Coast	16/02/2002 22:10	16.94	−99.93	37	6	Preventive	
53	Guerrero Coast	07/10/2001 22:39	16.94	−100.14	4	8	Public	65
52	Guerrero	06/03/2001 15:57	17.14	−100.1	32	9	Preventive	63
51	Guerrero Coast	05/03/2001 04:17	17.13	−100.06	32	8	Preventive	66
50	Guerrero Coast	14/04/2000 20:45	16.88	−100.35	9	5	Preventive	66

(continued)

Table 4.1 Continued

#	Region	NACIONAL SEISMIC SERVICE (SSN), UNAM				SAS FORECAST RESULT		
		Local date-time	Latitude	Longitude	Depth (km)	Sens. Op.	Alert range	Prevention time (s)
49	Guerrero	17/03/2000 18:50	17.08	−99.31	31	7	Preventive	68
48	Puebla-Oaxaca Border	15/06/1999 15:42	18.18	−97.51	69	9	Preventive	15
47	Guerrero	30/05/1999 04:58	17.26	−100.79	53	5	Preventive	68
46	Guerrero	24/04/1999 22:08	17.28	−100.8	27	4	Preventive	68
45	Guerrero Coast	07/09/1998 01:53	16.77	−99.67	12	3	Preventive	
44	Guerrero Coast	09/08/1998 11:18	16.87	−100.25	3	3	Preventive	
43	Guerrero Coast	17/07/1998 06:18	16.98	−100.16	27	7	Public	74
42	Guerrero Coast	05/07/1998 14:55	16.83	−100.12	5	6	Public	66
41	Guerrero Coast	09/05/1998 12:03	17.34	−101.41	18	4	Preventive	60
40	Guerrero	11/03/1998 08:13	17.01	−100.11	40	4	Preventive	
39	Guerrero Coast	21/12/1997 23:22	17.14	−101.24	5	5	Public	69
38	Guerrero Coast	26/08/1997 19:13	16.76	−99.00	28	6	Preventive	45
37	Guerrero	19/07/1997 02:34	17.22	−100.56	51	6	Preventive	56
36	Oaxaca-Guerrero Coast	14/07/1997 20:26	16.39	−98.74	11	3	Preventive	
35	Guerrero Coast	11/07/1997 17:23	16.76	−99.7	10	3	Preventive	
34	Low Balsas River	22/05/1997 02:50	18.41	−101.81	59	4	Preventive	
33	Guerrero	08/05/1997 10:58	17.32	−100.44	12	5	Preventive	55
32	Guerrero	23/03/1997 14:23	17.39	−100.88	31	4	Preventive	
31	Guerrero	21/03/1997 21:49	17.04	−99.76	30	7	Preventive	55
30	Michoacan Coast	11/01/1997 14:28	17.91	−103.04	16	7	Preventive	42
29	Guerrero	27/10/1996 03:15	17.11	−100.9	27	3	Preventive	
28	Guerrero	19/07/1996 04:00	17.35	−100.29	20	6	Preventive	
27	Guerrero Coast	15/07/1996 16:23	17.45	−101.16	20	6	Preventive	65
26	Guerrero Coast	13/03/1996 15:04	16.52	−99.08	18	6	Public	74
25	Guerrero Coast	16/09/1995 10:09	16.4	−98.69	10	2	Preventive	
24	Guerrero Coast	15/09/1995 21:20	16.3	−98.62	10	4	Public	

(continued)

Table 4.1 Continued

#	Region	NACIONAL SEISMIC SERVICE (SSN), UNAM				SAS FORECAST RESULT		
		Local date-time	Latitude	Longitude	Depth (km)	Sens. Op.	Alert range	Prevention time (s)
23	Oaxaca-Guerrero Coast	14/09/1995 08:09				5	Preventive	
22	Oaxaca-Guerrero Coast	14/09/1995 08:04	16.31	−98.88	22	9	Public	72
21	Oaxaca Coast	31/05/1995 06:49	15.97	−98.77	14	2	Preventive	
20	Guerrero Coast	14/04/1995 00:01	16.44	−99.09	15	6	Preventive	
19	Low Balsas River	10/12/1994 10:17	18.02	−101.56	78	6	Preventive	34
18	Guerrero Coast	29/10/1994 10:44	16.97	−99.89	24	9	Preventive	58
17	High Balsas River	22/05/1994 19:41	18.03	−100.57	23	8	Preventive	30
B		16/11/1993 19:11				1	Public (Fail)	
A	Guerrero Coast	24/10/1993 01:52				9	(Fail)	
16	Guerrero Coast	10/09/1993 04:50	16.57	−98.94	20	4	Preventive	70
15	Guerrero	29/07/1993 14:17	17.38	−100.65	43	4	Preventive	
14	Oaxaca-Guerrero Coast	15/05/1993 02:26	16.54	−98.65	20	4	Public	
13	Oaxaca-Guerrero Coast	14/05/1993 21:12	16.47	98.72	15	6	Public	73
12	Oaxaca-Guerrero Coast	14/05/1993 21:09	16.43	−98.74	20	6	Public	65
11	Guerrero Coast	31/03/1993 04:18	17.18	−101.02	8	4	Preventive	
10	Guerrero Coast	09/11/1992 20:13	16.89	−100.1	6	3	Public	
9	Guerrero Coast	04/11/1992 22:33	16.83	−99.66	8	2	Preventive	
8	Guerrero Coast	30/10/1992 02:16	17.14	−100.79	21	3	Preventive	
7	Guerrero Coast	16/10/1992 11:28	16.51	−99.17	17.4	5	Preventive	
6	Guerrero	02/08/1992 06:54	17.13	−100.3	25	6	Preventive	
5	Oaxaca-Guerrero Coast	07/06/1992 11:41	16.22	−98.87	5.2	3	Preventive	
4	Oaxaca-Guerrero Coast	07/06/1992 03:01	16.17	−98.9	2	3	Preventive	
3	Guerrero Coast	15/05/1992 02:35	16.83	−99.98	23	3	Preventive	
2	Guerrero Coast	26/04/1992 14:53	16.78	−100.09	15	4	Preventive	
1	Oaxaca-Guerrero Coast	16/10/1991 12:36	16.83	−100.24	5	1	Preventive	

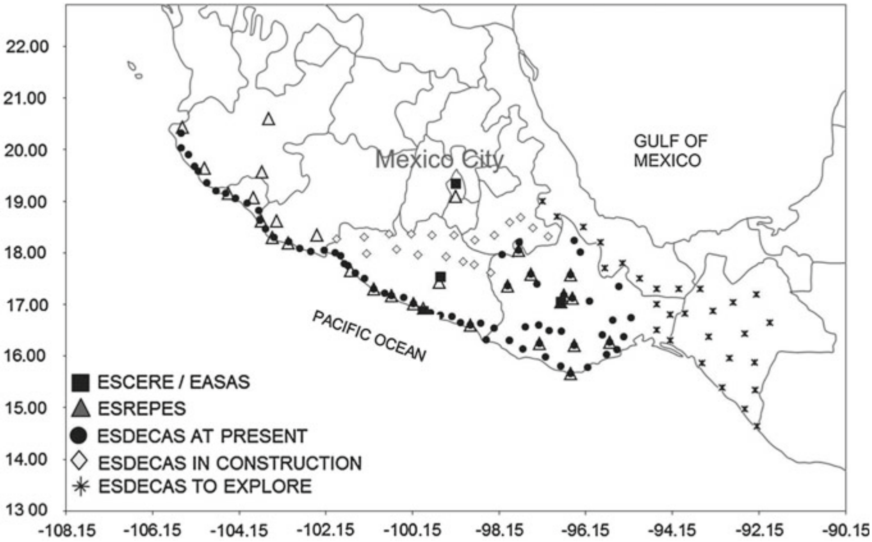

Fig. 4.2 Current topology of SASMEX

4.3 SASMEX Warning Broadcast

After the damages suffered in Mexico City during the 1985 earthquake, the law for Civil Protection and its bylaw were established. Among other requirements, it states that individuals and corporations must design action plans and emergency drills to mitigate vulnerability conditions and reduce the severity of disasters. Each action plan must be registered and certified in presence of municipal or local authorities that also supervise and enforce the regular practice of emergency response procedures (Suárez et al. 2009). The safety and security procedures, as well as the activity of each group in a certain facility, are established accordingly to the display of every building. Distribution of spaces and the identification of the risk and safety zones are considered (Official Gazette of the Federation, 2006; Mexico City Official Gazette 1996).

SASMEX for Mexico City (SAS) has been able to recognize a great number of seismic events, encode their range, and spread warnings as Public or Preventive Alerts. This service operates through three alternative technologies: remotely controlled audio switches installed in radio and TV stations operated by *SAS* that broadcast Public Alert warnings for strong earthquakes; radio receivers that radiate warnings when *SASMEX* emits Preventive and Public Alert signals of strong and moderate earthquakes; and beginning in December of 2008, receivers that include NWR-SAME technology capable of disseminating the Preventive and Public *SAS*'s alerts, as well as other natural disasters' warnings. These warning messages represent a useful service to reduce the vulnerability against a variety of risk conditions. During 2009, in accordance to the Civil Protection of Mexico City Officials

Table 4.2 SASO performance of earthquake early warnings since 2003–2012

#	Region	NACIONAL SEISMIC SERVICE (SSN), UNAM				SASO FORECAST RESULT		
		Local date-time	Latitude	Longitude	Depth (km)	Sens. Op.	Alert range	Prevention time (s)
33	Oaxaca	13/04/2012 08:07	16.22	−98.15	16	12	Public	38
32	Oaxaca	13/04/2012 05:10	16.11	−98.34	14	12	Public	40
31	Oaxaca	02/04/2012 12:36	16.27	−98.47	0	15	Public	40
30	Oaxaca	23/03/2012 19:58	16.26	−98.29	10	5	Preventive	
29	Oaxaca	22/03/2012 17:47	16.48	−98.29	24	13	Public	40
28	Oaxaca	22/03/2012 16:14	16.22	−98.47	9	8	Preventive	
27	Oaxaca	21/03/2012 05:36	16.51	−98.5	20	5	Preventive	
26	Oaxaca	20/03/2012 14:14	16.34	−98.28	15	12	Preventive	
25	Oaxaca	20/03/2012 12:36	16.21	−98.58	14	9	Public	
24	Oaxaca	20/03/2012 12:23	—	—	—	10	Public	
23	Oaxaca	20/03/2012 12:02	16.42	−98.36	15	22	Public	40
22	Oaxaca	04/03/2012 03:58	16.68	−94.4	108	3	Preventive	
21	Oaxaca	11/02/2012 23:56	17.36	−96.51	96	6	Preventive	
20	Oaxaca	15/01/2012 16:49	16.35	−97.83	5	10	Preventive	
19	Oaxaca	30/12/2011 09:47	16.91	−95.37	90	4	Preventive	
18	Oaxaca	16/12/2011 07:02	16.22	−98.3	5	8	Public	
17	Oaxaca	09/07/2011 07:43	15.87	−96.42	22	18	Public	
16	Guerrero	05/05/2011 08:25	16.61	−98.91	11	15	Public	
15	Oaxaca	14/04/2011 11:34	16.7	−95.09	102	5	Public	
14	Veracruz	07/04/2011 08:12	17.2	−94.34	167	23	Public	
13	Oaxaca	05/04/2011 15:18	16.32	−96.15	15	4	Public	
12	Oaxaca	04/02/2011 11:32	17.25	−96.56	76	3	Public	
11	Oaxaca	30/06/2010 02:22	16.22	−98.03	8	22	Public	
10	Oaxaca	16/04/2010 05:01	16.14	−98.41	10	4	Public	

(continued)

Table 4.2 Continued

		NACIONAL SEISMIC SERVICE (SSN), UNAM				SASO FORECAST RESULT		
#	Region	Local date-time	Latitude	Longitude	Depth (km)	Sens. Op.	Alert range	Prevention time (s)
9	Oaxaca	08/02/2010 18:48	15.9	−96.86	37	14	Public	
8	Chiapas	05/07/2007 20:09	16.35	−93.99	113	5	Preventive	40
7	Oaxaca	15/03/2007 07:13	16.08	−97.26	15	6	Preventive	
6	Oaxaca	24/01/2007 22:23	16.21	−97.14	6	2	Preventive	
5	Oaxaca	19/08/2006 00:41	15.91	−97.3	52	8	Public	
4	Oaxaca	15/12/2004 02:05	16.05	−95.43	10	4	Preventive	
B	Oaxaca	18/08/2004 04:03	16.3	−95.12	63	9	(Comx Fail)	
A	Veracruz-Oaxaca	07/08/2004 06:49	17.06	−95.44	112	10	(Fail)	
3	Oaxaca-Guerrero Coast	14/06/2004 17:54	16.31	−98.06	10	6	Public	30
2	Oaxaca Coast	13/01/2004 15:28	16	−97.16	14	10	Public	
1	Oaxaca	13/01/2004 13:50	16.01	−97.16	14	6	Preventive	

(*Secretaría de Protección Civil del GDF*), access to the use of the radio receiver makes mandatory to have an Internal Civil Protection Plan and practice emergency response procedures frequently.

Mexico City since 1992, have pioneered in the use of the *SAS* (Espinosa-Aranda, et al., 1998) beginning with twenty six Elementary Schools of the Ministry of Education of Mexico City (*Secretaría de Educación Pública de la Ciudad de México*). Each facility has an internal plan for civil protection that is systematically practiced and executed whenever *SAS* sends a warning signal to the radio receiver. From 1993 to the date, as stated before, more than 80 elementary, middle, and higher education institutions have been furnished with this equipment.

The Public Electric Transportation System and the METRO have used the *SAS* warnings by means of radio receivers in their control center since 1992, but they do not share the signals with the passengers. In case of a seismic warning, the manager of the control center gives proper instructions for the train operators to stop in the nearest station, or delay their start and keep the doors open for passengers' safety. This is an internal security and emergency procedure that has given great use to the 60 s that *SAS* can offer.

In Mexico, the transmission of radio and TV seismic alert signals began in 1993, through most of the partners of the Association of Broadcasters of the Mexico Valley (*Asociación de Radiodifusores del Valle de México A.C.*) and TV channels 11, 22, 13, and channel 34 in Toluca Valley. To be able of properly disseminate the signals, the broadcasters accepted the use of a remotely controlled switch operated by *SAS*, which substitutes the regular signal for the official alert signal during 60 s in case of a strong earthquake warning. The effectiveness of this resource is optimal in top rating periods because a greater part of the population is warned and can start predefined preventive actions. To date, twenty eight AM, FM and TV channels spread the warnings in Mexico City and Toluca Valley as well as nine radio and two TV stations in Oaxaca City. Also, Emergency Response and Civil Protection Institutions use the radio receiver to prepare emergency vehicles and start the evacuation of their parking lots. There are 13 institutions that use this equipment, including the Red Cross and Firefighters.

Nowadays, *SASMEX for Mexico City (SAS)* serves more than 240 public and private buildings in Mexico City; they receive seismic alert signals through the radio receiver. To guarantee the dissemination of the warning sound, some buildings have displayed loudspeakers arrays where their correct performance should be verified.

In addition to start preventive measures, *SASMEX* signals are used to trigger structural health recording procedures to identify possible damage in buildings.

Since March 27, 2009 at 02:48:32 (local time), when *SAS* emitted a "Preventive Alert" signal, anticipating the effects of the M5.3 earthquake from the coast of Guerrero. Then for the first time *SAS* used the NOAA-SAME technology validating the effective use of this resource. At that time eight monitoring NOAA receivers successfully reacted and provided 58 s of Prevention Time. Nowadays with a technical enhancement to expedite reaction, by reducing receiver's response time, the NWR-SAME with SARMEX protocol helps to mitigate the seismic vulnerability in Mexico.

On April 27, 2009 at 11:46:45 (local time), *SAS* emitted a signal of "Preventive Alert", anticipating the effects of the M5.7 earthquake from the coast of Guerrero. *SAS* confirmed the adequacy to use the NOAA-SAME technology in the city for this purpose. *SASMEX* in Oaxaca has a similar range of users to the one of Mexico City, with the exception of automatic powerful loudspeakers installed in public spaces, which can be heard in the public squares of Oaxaca City. As in Mexico City, Oaxaca and Toluca, in Chilpancingo and Acapulco both Guerrero State cities, received *SAS* warnings in more than 100 users, among radio, TV stations, schools, emergency response institutions and others in 2007. On 20th March 2012, for the earthquake M 7.4 of Oaxaca, SASMEX broadcasted Public Alert Warning to Oaxaca, and Acapulco cities, Chilpancingo and Mexico City, were activated with Preventive Alert Warning range, due to communication issues. On April 13th 2012 SASMEX activated two earthquake early warnings at 05:10:03 08:07:23 (Local Time) for the seismic event M5.2 and 5.1 respectively; with that seismic events, SASMEX for Mexico City worked for first time as an interconnected system.

4.4 The Punta Maldonado Earthquake

The earthquake was located between SAS and SASO seismic station arrays in the Punta Maldonado region with Mw = 7.4, it is noteworthy that on the date of this event, these systems had not yet achieved sensor interface through the link between Mexico City and Oaxaca therefor SAS and SASO's seismic sensor arrays operated in separately way.

The earthquake was detected by 32 seismic stations in Oaxaca and seven in Guerrero. During the first 48 h more than 100 seismic events were recorded under the Llano Grande LG01 seismic station which was closest to the epicenter (Fig. 4.3).

Llano Grande seismic station was the first to detect the earthquake, it is located within 25 km of the hypocenter, the SP time observed was of about 2.6 s. Llano

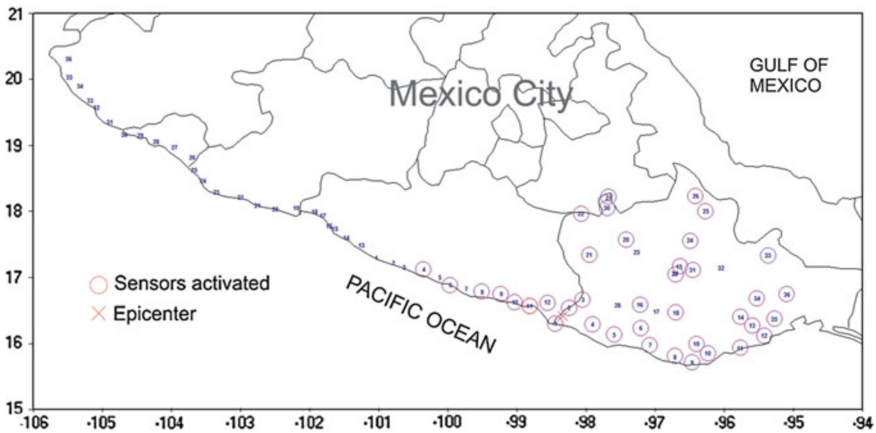

Fig. 4.3 Sensors Activated (*circles*) during the $Mw = 7.4$ earthquake on March 20th, 2012

Table 4.3 Main sequences of SASMEX seismic sensors performance during the Mw = 7.4 earthquake on March 20th, 2012

Local time	Station	Network	Forecast result
12:02:56	LG01	SASO	Strong
12:02:58	MT02	SASO	Strong
12:02:58	Easas Oaxaca	SASO	Public
12:02:59	HU12	SAS	Strong
12:03:03	MA12	SAS	Strong
12:03:03	Easas Acapulco	SAS	Strong
12:03:09	CR10	SAS	Moderate
12:03:09	Easas Chilpancingo	SAS	Preventive
12:03:09	Easas Mexico City	SAS	Preventive
12:03:14	MA11	SAS	Strong
12:03:14	Easas Chilpancingo	SAS	Public

Grande transmitted its power and slope parameters calculated for 2*(S-P) to the city of Oaxaca at 12:02:56, a little more than 5 s after detecting the onset of the P wave, and estimated the event developing as a strong earthquake. The above information began the process of activation of Alert for the city of Oaxaca. MT02-station "Mártires de Tacubaya" confirmed the process, at 12:02:58, 2 s after the previous one, and calculating the parameters of slope and amplitude in the period 2*(S-P) approximately 12 s, conveyed them to the City of Oaxaca, it also predicted strong earthquake, which was the confirmation of the process and prognosis Public Alert activated in Oaxaca.

In Acapulco, the field station HU12-Huehuetán transmitted its parameters with a strong earthquake forecast to 12:02:59. The station was confirmed MA11-Marquelia at 12:03:03 and after calculating the parameters at time 2*(S-P) as HU12, transmitted its parameters a second after the event detected at the beginning of the wave packet P (Table 4.3, Fig. 4.4). This led to the city of Acapulco earthquake also will predict and deliver Strong Public Warning.

Risk parameters and HU12-MA11-Marquelia Huehuetán must be received in Chilpancingo and Mexico City, but due to interference in the stretch of Acapulco and Chilpancingo caused the MA11 data were not recognized. HU12 data were received at 12:02:59 and CR10-"El Carrizo" seismic station transmitted at 12:03:09 parameters once estimated slope parameters and energy in the period 2*(SP) of approximately 16 s (Table 4.2). The station CR10 predicted the earthquake as Moderate. Although, combining strong and moderate earthquake determinations to activate the alert as Preventive, which was issued at Chilpancingo and Mexico City at 12:09:09? During the earthquake, the seismic station Marquelia aired a second time hazard signal, Chilpancingo changed the forecast to Public alert at 12:03:14. The time of opportunity for the city of Acapulco was 25 s, to Oaxaca City 45, to Chilpancingo was estimated to 45 s and finally in Mexico City was of 80 s.

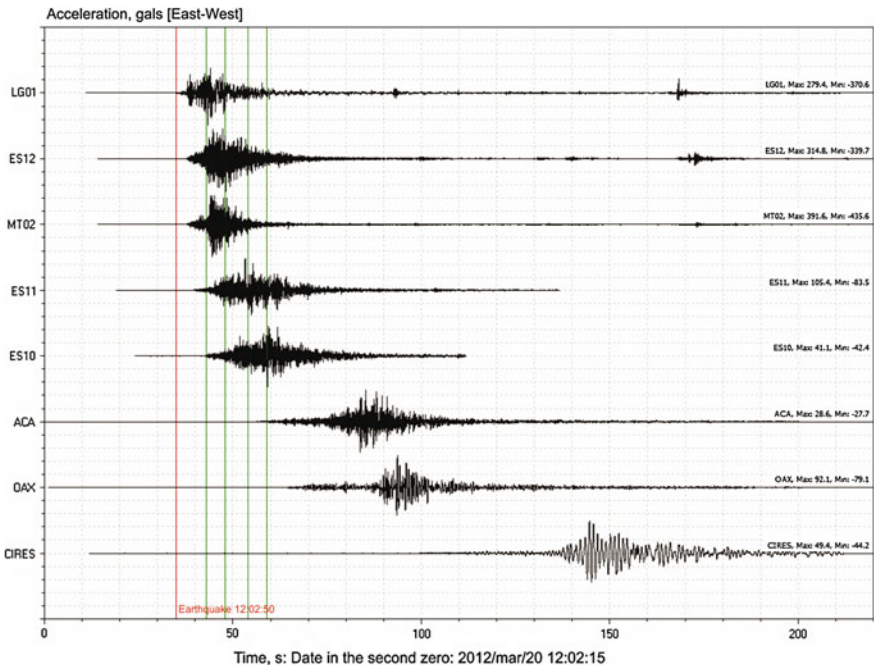

Fig. 4.4 SASMEX performance during the Mw = 7.4 earthquake on March 20th, 2012

4.4.1 Human Response After Activation of the Seismic Alert in Mexico City

During the Preventive Alert warning in Mexico City and given the opportunity time of 80 s civil protection were instrumented procedures and additionally it served to check the effectiveness of the NWR radio receiver SARMEX that had been installed in 640 public schools. Several radio and television broadcasting companies warned their audiences that the alert had been activated and warned with 80 s of opportunity that an earthquake was coming.

In government offices, especially at the House of Representatives, the Federal Electoral Institute documented the reaction of civil defense personnel as well as of the people who were in those buildings; they made use of the seismic alert drills carried out every few months for the case of occurrence of an earthquake.

4.5 Discussion

Since damaging earthquakes are rare, the development of this technological resource has deemed necessary to optimize the reliability and availability indexes of their basic elements in order to guarantee the effective dissemination of alert warnings in the occurrence of damaging events including forecasting criteria of seismic risk. The *SASMEX* system has its own designs and self-evaluation procedures as well as a continuing technological improvement program aimed to have an assurance of its services. In the design, development and operation of *SAS* and *SASO*, now SASMEX, it is acquired the compromise to improve continuously their subsystems that conform them as well as the processes of detection, computation, communication, forecast and effective broadcast of the warnings in case of earthquake as such as the low-cost NWR-SAME radio receivers with Public alert protocols, SARMEX that includes protocol which improve the activation of NWR receiver for immediately to respond in case of earthquake in order to have the longest time of opportunity possible.

The SASMEX in the process of enlargement and integration envisions a future with federal government support extended to the cities of Chiapas and Veracruz. While Mexico City by soil characteristics and demographics are considered a risk seismic region, there are neighboring cities of seismic hazard zones, which must have notices Seismic Alert System of Mexico. The SASMEX during the earthquake of March 20, 2012, M 7.4 generated earthquake early warnings to Mexico City, Toluca, Acapulco, Chilpancingo and Oaxaca City, giving a time of opportunity at least 25 s in the city of Acapulco, and more than 80 s in Mexico City which warning was disseminated SASPER receptors and SARMEX radio receivers.

Public-oriented discussions together with the proper detection of the earthquake, the reliability of message transmission and the risk evaluation constitute necessary elements in the systems of early warning systems. However, if dissemination and training campaigns launched among the population exposed to natural hazards continue to be insufficiently funded, any early warning system will be exposed to failure to comply with its main objective for which it was designed (United Nations 2006). The technological development of early warning systems applicable to earthquakes is continuously improving and it is convenient to analyze the full spectrum of earthquake early warning. Nevertheless, other high-priority tasks must be reinforced by the authorities, like the diffusion and knowledge of the seismic danger around the city, the continuous program of prevention when the signal of seismic alert is emitted.

Acknowledgments The authors deeply acknowledge the support received from the Mexico City Government Authorities since 1989, originally through its *Secretaría de Obras y Servicios, Comité Directivo del Sistema de Alerta Sísmica,* the *Coordinación General, Secetaría de Educación, Instituto Local de Infraestructura Física Educativa and Secretaría de Protección Civil de la Ciudad de México,* who have decided to apply this technological development, proposed after our 1985 earthquake disaster experience, with the aim to mitigate the seismic vulnerability in the metropolitan population of the Mexico City valley. We are also grateful to *Autoridad del Centro Histórico de la Ciudad de México,* by its valuable sponsorship required to install the radio transmitters system used to disclose via low-cost receivers of the EAS-SAME-Public Alert system the warnings issued by the *SAS* system. We would also like to thank the *Secretaría de Educación Publica* (Public Education Ministry), that supported the *SAS* experimental program since 1992 in some schools of Mexico City; the valuable support from the *Asociación de Radiodifusores del Valle de México*, that since 1993 broadcasts the automatic warnings issued by the *SAS* to the general public; and, the government of Oaxaca, that in 2002, through its *Unidad Estatal de Proteccion Civil*, promoted the *SASO* design and development. Finally but not less, to *Teléfonos de México* (TELMEX) and of *Comisión Federal de Electricidad* (CFE) for their valuable infrastructure support that has expedited the installation and exploitation of these *SAS* and *SASO* resources. Finally we thank the *Coordinadora Nacional de Protección Civil*, *Centro Nacional de Prevención de Desastres (CENAPRED)* and *Secretaría de Seguridad Pública* for its decision and support to coordinate several activities such as to use their telecommunications infrastructure as redundant via to guarantee the SASMEX critical information.

References

Espinosa-Aranda JM, Jimenez A, Contreras O, Ibarrola G, Ortega R (1992) Mexico city seismic alert system. International symposium on earthquake disaster prevention, proceedings CENAPRED-JICA, vol I. Mexico, pp 315–321

Espinosa-Aranda JM, Jimenez A, Ibarrola G, Alcantar F, Aguilar A, Inostroza M, Maldonado S (1995) Mexico city Seismic Alert System. Seismol Res Lett 66(6):42–53

Espinosa-Aranda JM, Rodriguez FH (2003) The Seismic Alert System of Mexico city. International handbook of earthquake and engineering Seismology 81B, International association of Seismology & physics of the earth's interior, committee on education

Espinosa-Aranda JM, Cuellar A, Ibarrola G, Garcia A, Islas R, Maldonado S, Rodriguez FH (2009) Evolution of the Mexican Seismic Alert System (SASMEX). Seismol Res Lett 80(5):694–706

Espinosa-Aranda JM, Cuellar A, Rodríguez FH, Frontana B, Ibarrola G, Islas R, García A (2010) The Seismic Alert System of Mexico (SASMEX): progress and its current applications. Soil Dyn Earthq Eng 31:154–162

Goltz JD, Flores PJ (1997) Real-time earthquake early warning and public policy: a report on Mexico city's Sistema de Alerta Sismica. Seismol Res Lett 68(5):727–733

Kanamori H (2003) Earthquake prediction: an overview. International handbook of earthquake and engineering Seismology 81B, International association of Seismology & physics of the earth's interior, committee on education

Lee WHK, Espinosa-Aranda JM (1998) Earthquake early warning systems: current status and perspectives. International IDNDR-conference on early warning systems for the reduction of natural disasters, Potsdam, Federal Republic of Germany, 7–11 Sept 1998

Mexico City Official Gazette (1996) Reglamento de la Ley de Protección Civil para el Distrito Federal (1996), Gaceta Oficial del Distrito Federal Mexico, 21 Oct 1996

Official Gazette of the Federation (2006) Ley General de Protección Civil (2006) Diario Oficial de la Federación, Mexico, 24 April 2006

Suárez G, Novelo D, Mansilla E (2009) Performance evaluation of the Seismic Alert System (SAS) in Mexico city: a seismological and social perspective. Seismol Res Lett 80(5): 717–726

United Nations (2006). Global Survey of Early Warning Systems An assessment of capacities, gaps and opportunities towards building a comprehensive global early warning system for all natural hazards. United Nations Inter-Agency Secretariat of the International Strategy for Disaster Reduction (UN/ISDR)) Final Version