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APPLICATION OF STRONG MOTION DATA FOR EPICENTRAL DETERMINATION OF EARTHQUAKES

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SUMMARY

Epicentral parameters of a few earthquakes have been examined which were based on the P and S wave arrival time data obtained recently through the Strong Motion Instruments. It is inferred that P and S wave arrival times from these instruments provide valuable additional data for epicentral determination either independently or in combination with that from seismographs and may be included by the International Seismological Centre, U. K. when available.

1. INTRODUCTION

Strong motion instruments are being installed primarily for generating acceleration data for engineering applications. Of late, the addition of accurate timing system through an internal time coda generator has increased the utility of data manifold even for seismological research. In particular, deployment of strong motion arrays has shown that useful data can be obtained in a reasonably short time frame and better studies pertaining to source dynamics in the near field region can be made. Another application pertains to the epicentral determination of earthquakes since the arrival times of P and S waves from several nearby stations may be available.

The object of this paper is to examine the extent to which the data from the accelerographs in combination with that from the seismographs or independently can be useful for epicentral determination of earthquakes.

2. STRONG MOTION NETWORKS

Strong motion instruments are triggered only when the threshold value set at the site is exceeded otherwise they remain in operative.

It is estimated that more than 6000 accelerographs are deployed worldwide. Current strong motion instrumentation is of two types, analog film recording and direct digital recording. Analog recorders are generally used for applications in isolated or remote networks where the anticipated data yield is low and a stable supply of electric power is not readily available. Such instruments may, however, some time miss the first arrival. Digital recorders (solid state core memory or cassette) are now being used in arrays due to greater accuracy (accurate timing), high resolution and dynamic range, log noise, retention of pre-event information and ease of access to computers for analysis (eliminating numerous sources of noise). However, the number of instruments with the timing system is relatively small, Deployment of arrays in seismically active regions has been accelerated after the International Workshop on Strong Motion Instrument Arrays held in Honolulu in May 1978. As per recommendation at this Workshop, earthquake prone countries individually and collectively make a concentrated effort to establish a comprehensive world wide system of specialised strong motion earthquake instrument arrays capable of resolving the nature of the earthquake

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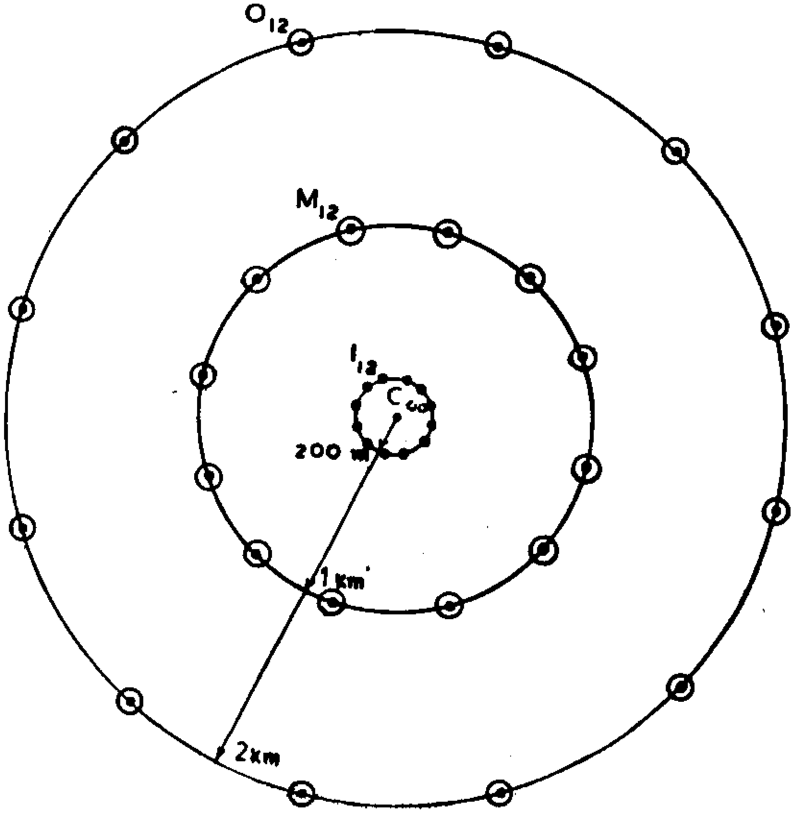
source mechanism, wave propagation and local site effects. With these objectives, a few such strong motion arrays have been installed and valuable data is being obtained.

2.1. Strong motion arrays in Taiwan

Since September 1980, large broad band digital array of strong motion accelerographs called SMART-I has been operating in a highly seismic region of Taiwan under a joint programme between the University of California, Berkely and Academic Service, Taiwan, (Fig. 1) The array is a two dimensional surface array and consists of a Central Element and three concentric circles each with 12 accelerographs having a common time base and radius of 200 metres, 1km and 2 km respectively. The accelerogrphs contain 3 component force balance accelerometers (SA-3000) connected to a Sprengnether DR 100 recorder with a sampling rate of 100 per channel. (Bolt et al, 1182, Bolt, 1987). The array eas been triggered by several earthquakes and the largest earthquake ($M_g = 7.8$) recorded so far occurred on November 14, 1986 which had its epicentre 79 km to its south-east.

2.2. Park Field Strong Motion Array

This array has been installed in the vicinity of park field in Central California. The array configuration forms limbs oriented perpendicular to the San-Andreas fault and a Central zone of stations paralleling the fault.



Figure—1

2.3. Strong motion Arrays in Japan

It has been reported that more than 20 strong motion arrays have been installed in Japan. At the Fuchu area west of Tokyo, two types of the array observational systems have been installed i. e. the vertical array of four triaxial accelerometers and the horizontal array of five velocity meters.

2.4. Strong motion Array in China

Under a joint research project between China and USA, a small array of four kinemetrics PDR-1 digital accelerographs has been installed in a small area of about 0.3 km^2 near the Luanxian and Taoyuan faults which is seismically active. Useful records were obtained at all the four stations through the triggering of 8 earthquakes of magnitude from 2.3 to 5.3.

2.5. Strong motion array in Himachal Pradesh and Shillong, India.

2.5. 1. Kangra Array (Himachal Pradesh, India) is trending northwest to southeast having a linear dimension of about 240 km and is parallel to the regional strike of main boundary faults. The width of the array in a direction transverse to the geological features varies from about 40 to 80 km. The interstation spacing varies from 7 to 21 km. Fig. 2 shows the location of the Array in Himachal Pradesh (Chandrasekharan, 1987).

2.5.2. Shillong Array : Keeping in view the highseismicity around Shillong, a comb shaped array comprising 20 instruments has been designed along Dawki fault (which is of strike slip type) between latitudes 20°N and 26°N with three projcted legs. This array merges in the east with a two dimensional array of 25 instruments northeast-southwest trending Haflong thrust (Chandrasekharan, 1987). The number of instruments may be increased in the near future to cover the entire northeast Indian region where a damaging earthquake is not unexpected, keeping in view the past history of great earthquakes and the tectonics of the region. India Meteorological Department has also installed about a dozen analogue accelerographs at the national network of stations. Time code generator is also being provided in the instruments.

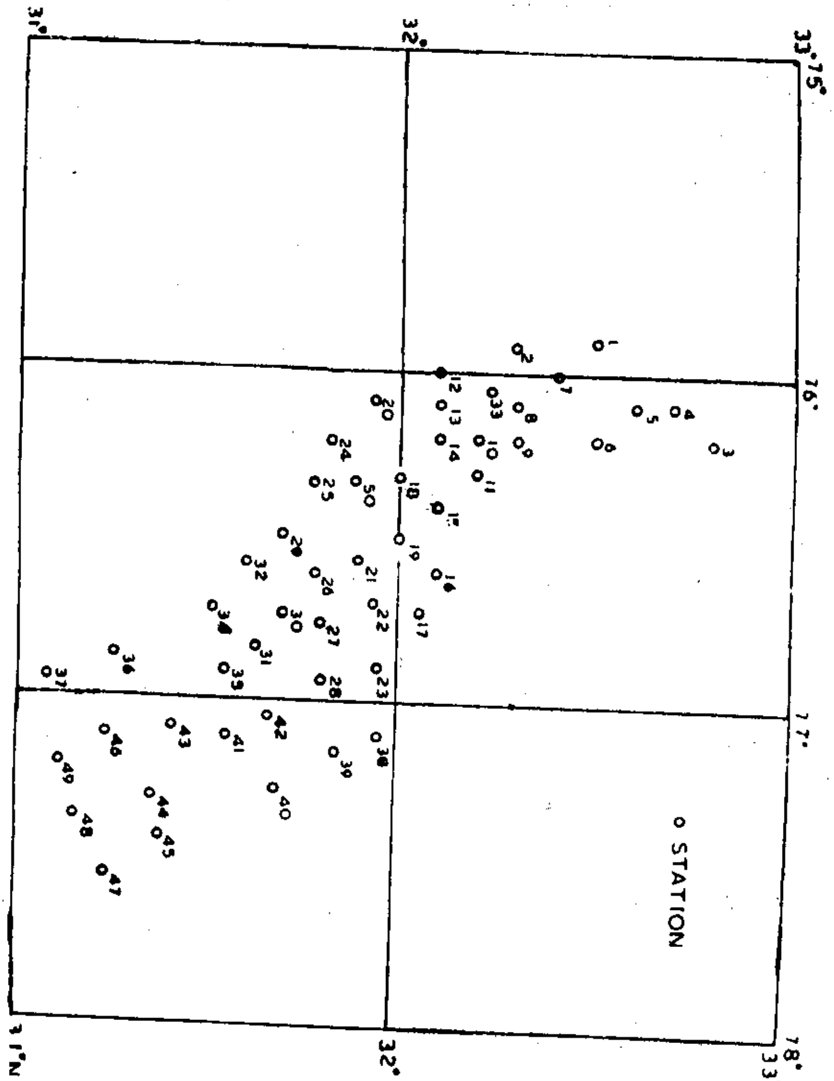
A few strong motion instruments in Kashmir, Himachal Pradesh and northeast India have already been triggered by earthquakes in the recent past.

3. Epicentral parameters of earthquakes using P and S wave data from strong motion instruments

3.1. Mexican earthquakes, 1985

Table 1 gives the epicentral parameters of the main earthquake of 19 September, 1985 in Mexico and its largest aftershock of September 21.

The epicentral location of the main earthquake was obtained from strong motion data through an array of digital strong motion stations



Figure—2

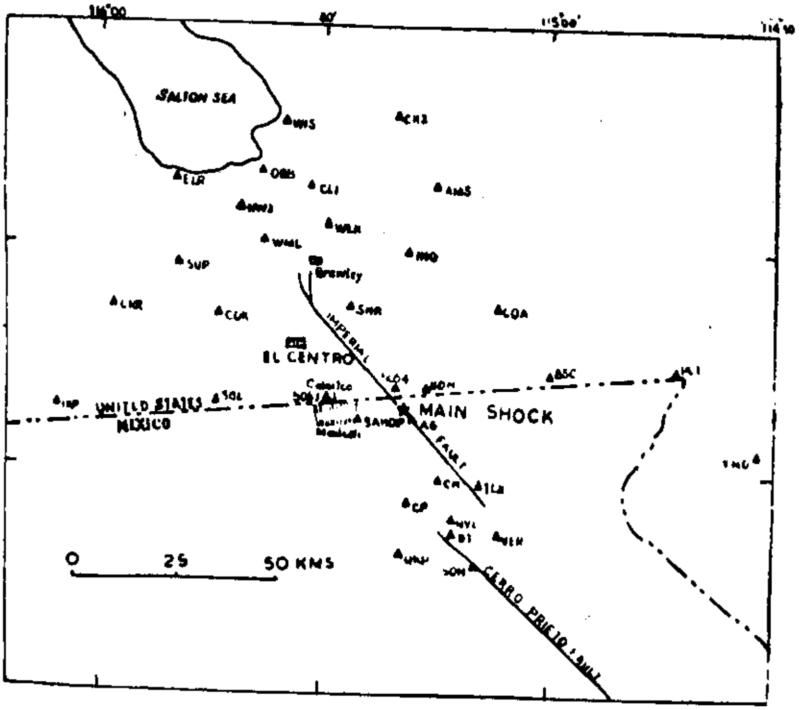
which were set up along the coast of Michoacan and Guervero in anticipation of large earthquakes in the region, (UNAM, 1986). Immediately after the main earthquake, a network of portable seismograph was also set up in the epicentral area. The epicentral parameters of the largest aftershock of September 21, were based on both strong motion and portable seismograph data (Singh and Suarez, 1986). It would be noted that there is a difference of about 20 to 40 km between the ISC epicentres and those based on local netwnrk. Also, the focal depths for the two events reported by NEIC and ISC appear to be large particularly when Pg and Sg phases were recorded. It is, however noted that there is an agreement between the focal depths reported by ISC/NEIC and these determined ftom Pp phases. The differences in the focal depths between those determined from synthetic wave form modelling and that from Pp phases are significant but detailed discussipn is beyond the scope of this paper.

Between 24 and 30 September, 1985 digital strong motion instruments were installed in the epicentral region of the great Mexican earthquakes to aftershocks. They provided useful data for aftershocks through the triggering of several shocks. It was noted that all the accelerograms had triggered with the arrival of Sg phase. It was noted that P wave was nearly indistinguishable from the noise in the raw data. However through the use of Butterworth two pole band pass filters, from the filtered accelerograms enabled to identify P waves also if the pre-event memory had been set at 10 seconds. This phase would correspond to Pg waves. Thus the indentification of Pg and Sg through the accelerograms restricted the focal depth of the events to granitic layer instead of 33 km or normal as is often reported by NEIC.

3.2. October 15, 1979 Imperial Valley earthquake (ML=6.6)

By pooling the arrival time Data from U.S. and Mexican networks and strong motion records, the epicentral parameters of the Imperial Vallex earthquake of October 15, 1979 were determined. A total of 31 P wave and 4 S wave arrival times within 30 km gave considerable confidence in the calculated focal depth.

Most arrival times for this shock were read from 22 stations in the Imperial Valley seismic network operated jointly by the U.S. Geological Survey and the California Institute of Technology. South of the epicentre of Mexico, times were available from 5 permanent stations operated by the Centro de Investigacion Cientifica Educacion Superior de Enscnada (CICESE). Data from two strong motion stations in USA and 5 installed by the Universidad Nactional Antonoma de Mexico (UNAM) and the University of California, San Diego (UCSD) were used. Their locations are shown on the map (Fig. 3).



Figure—3

The arrival times at the CEDAR and RESCEP short period telemetry systems for two arrays in the network were read with a precision of ± 0.2 and ± 0.10 sec respectively. The strong motion instruments are film records with WWVB time coding that alow arrival times to be picked up with an accuracy of ± 0.10 s. The UNAM/UCSD strong motion statipns (with the exception of a station SAHOP) record digitally on magnetic tape with timing by an internal clock. Time corrections for assumed linear clock drift over an average period of 1 week were approximately 2 s at each site. Arrival times were read with a precision of ± 0.04 s. The strong motion instrument at station SAHOP is a film recorder with no absolute timing and (S—P) interval was used. The arrivals at strong motion stations CH and DT are inconsistent with the times at the surrounding stations; possibly owing to errors in the time correction and their data was not used. In all, a total pf 31 P wave arrivals 4 S-wave arrivals (from the strong motion records) and

1 S-P time were used. The velocity model for the study based on Mooney and Mc Mechon (1982). This model gave the smallest travel time residuals. However, as the model includes a sedimentary cover, a correction ot—0.80 sec had to be applied to the times for all stations situated on bed rocks. This was based on the average travel time residual at the bed rock sites, as calculated for a preliminary hypocentral location.

The hypocentral parameters were computed using the HYPO 71 computer programme of Lee and Lahr (1975). Arrival times at stations within 40 km of the epicentre were assigned distance weights of 1 and distant stations were assigned progressively lesser weights such that at 80 km, the weight was reduced to zero.

The best solution thus obtained was as follows :

Origin Time	23 16 54.29 GMT
Epicentre	Lat. 38°31.61'N, Long.115°18.53 'W.
Focal depth	9.96 km.

ERH and ERZ values were found as ± 0.4 km mnd ± 0.2 km respectively.

Chavez et al (1982) conclude that P and S wave arrival times within 30 km permit considerable confidence in a calculated focal depth of 10.0 km and the solution is well constrained by the broad azimuthal coverage (283°) and by the data from three stations that are within 7 km of the epicentre.

3.3. Earthquakes recorded by the SMART 1 Array, Taiwan

Table 2 shows the epicentral parameters of 15 earthquakes recorded during one year of the operation of SMART 1 array (Bolt et al. 1982), Or these, the earthquake of November 14, 1930 (ML = 5.9) wks only 10 km from SMART1 and so it was looated almost right under the array. Sixteen out of 21 operating instruments were triggered. Both S and P waves as well as S waves across the Array was observed, consistent with the near vertical incidence of the waves.

3.4. Nahanni earthquake (MS=6.6), Canada

Three SMA-1 accelerographs were installed near the centre of activity in northwest Territories of Canada after the above earthquake. On December 23, 1985, a second large earthquake o, MS=6.9 occurred at nearly the same location and triggered the strong motion instruments. Shortest hypodentral distances to the point of rupture initiation appear to be 8 to 10 km or less. During the 10 week deployment, the temperature in the area dipped to about—40°C.

The P-wave energy on all three records was well above the trigger threshold of the SMA's is about 50 ms. The observed times after corrections, together with data from the Canadian seismic network gave the following epicentre for the December 23, earthquake.

Origin time :	06 16 06.5 UTC
Epicentre :	62 187°N, 124.243-W
Focal depth :	6.0 km

3.5. Dharamsala earthquake of April 26, 1986

The earthquake of April 26, 1986 (Magnitude M_L =5.4) triggered accelarographs of the Himachal Pradesh Array (Chadrasekharan, 1987). Using the absolute arrival times of Pg and Sg waves from this array, the epicentre could be better located as compared to data from seismoraphs only. Table 3 shows the epicentral parameters of this earthqake which has been determined using USGS HYPO 71 computer programme after modifying the crustal velocity model of Kamble et al (1974) by adding the sedimentary layer. Pg and Sg times from six accelerographs could be read in addition to those of Pn and Sn velocities from nearly seismological stations through which the detection threshold has been been reduced to magnitude 2 in Himachal Pradesh (Srivastava et al, 1987). The focal depth of this earthquake was reported by NEIS as 33 km for this earthquake while the results based only on the strong motion data gave the focal depth as 5 km (Srivastava, 1987). Using a combination of larger data base from nearby seismological stations as well as strong motion records, the focal depth was found to be 13 km with the error parameters, RMS, ERH, ERZ as 0.61, 2.5 and 1.1 respectively. Keeping in view, the depth of the granitic layer in the region as 22 km and the clarity with which Pg and Sg phases were recorded at the nearby stations, the depth range of 5 to 13 km (whether based only on strong motion data or in combination with seismographs narrowed down to a more plausible value than that reported by NETS as 33 km.

This epicentre was also found to be closer to the meizoseismal area (Gupta et al, 1986) although detailed analysis is still in progress.

3.6. Koyna earthquake December 10, 1967

The author compared the crustal velocity model deduced by India Meteorological Department and the National Geophysical Research Institute, Hyderabad for Koyna region (Srivastava, 1988) employing different techniques based on Deep Seismic Sounding data. A focal depth of 8 km for the main Koyna earthquake of December 11, 1967 was found if S-phase from accelerogram data is included instead of about 2 km which could raise a controversy.

3.7. Srinagar earthquake of February 8, 1988

Accelerograms data was obtained at IMD station at Srinagar tron earthquake of magnitude 4 on February, 1988. S-phase could be read with greater clarity than that from MEQ-800.

4. Results

A synthesis of the above would indicate that the arrival times of P and S waves from the accelerograhs could be used to the same advantage for epicentral determination as the data from the seismographs. Addition of P and S times from the accelerographs, may in some situations provide better control on the focal depth of earthquakes if they are located very close to epicentral region. This inference, however is tentative unless ISC determines the epicentral parameters of several well recorced earthquakes with and without strong motion data and then compare the resits. While this study could perhaps be linked to the other seggestions like change of velocity model from Jeffreys Bullen to that of Herrins (1968) and needs to await the triggering of more accelerographs by earthquakes, the advantages of using strong motion P and S arrival times in combination with those from seismographs is established and could be used by ISC.

Conclusions

The P and S arrival times from strong motion records provide valuable data set for the epicentral parameters of earthquakes and may be included by ISC for routine analysis.

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TABLE 1

EPICENTRAL PARAMETERS OF MEXICAN EARTHQUAKE OF SEPTEMBER 1985 AND ITS LARGEST AFTERSHOCK

Date		Origin Time h	m	s (GMT)	Epicentre °N	°W	Focal Depth (km)	Source
19.9.1985	(i)	13	17	50.1	18.54	102.37	29	ISC
	(ii)	13	17	47.3	18.2	102.5	28	NEIC
	(iii)	13	17	49.05	18.141	102.707*	16	Singh and Suarez (1986)
21.9.1985	(i)	01	37	15.1	17.81	101.69	42	ISC
	(ii)	01	37	13.4	17.8	101.6	31	NEIC
	(iii)	01	37	11.75	17.618	101.815*	20	Singh and Suarez (1986)

* Depth constrained from synthetic modelling of P-waves.

TABLE 2
EARTHQUAKES RECORDED BY THE SMART 1 ARRAY

Event No.	Origin	Time (GMT)	Epicentre Long. (E)		Epicentre Lat. (N)		Depth (km)	Mag.	Azim	△	T/I*	Max.	Acc.	(gal)
			deg.	min.	deg.	min.			(deg.)	(km)		V	EW	NS
1	1980.10.18	00 : 08 : 22.9	121	52	24	17	8	5.8	166.5	45.0	16/21	14.8	21.1	23.7
2	1980.11.14	13 : 37 : 4.0	121	47	24	35	62	5.9	164.2	10.0	16/21	29.7	69.7	78.7
3	1980.11.14	13 : 38 : 15.8	121	49	24	34	59	5.6	152.1	12.5	13/21	10.7	22.9	24.6
4	1981. 1.24	14 : 10 : 31.7	121	44	23	53	43	5.8	181.7	87.5	2/27	2.4	8.1	9.0
5	1981. 1.29	04 : 51 : 36.0	121	53	24	26	11	6.9	153.8	30.0	27/27	64.5	158.2	244.1
6	1981. 2.27	02 : 27 : 33.9	121	52	24	33	76	5.8	140.4	17.2	10/27	4.4	13.6	12.2
7	1981. 3. 2	12 : 13 : 46.2	121	25	22	57	9	6.9	190.8	192.6	3/27	2.7	6.4	10.5
8	1981. 3.10	08 : 24 : 51.2	121	47	24	44	7	4.4	15.4	7.0	19/27	16.0	23.5	34.5
9	1981. 3.22	21 : 25 : 32.5	121	49	24	45	11	3.8	30.9	9.7	12/28	13.1	22.8	19.1
10	1981. 5. 3	19 : 19 : 51.3	121	59	24	42	68	5.3	82.4	21.5	10/28	16.6	21.0	18.3
11	1981. 6. 1	11 : 53 : 44.2	121	50	24	23	2	5.3	165.5	32.5	8/28	10.1	13.2	15.0
12	1981. 8.20	19 : 03 : 28.1	121	45	24	41	0.1	4.7	286.7	1.8	18/36	22.9	23.3	35.5
13	1981. 8.20	20 : 55 : 6.6	121	46	24	43	0.3	3.9	23.1	4.3	14/36	13.4	25.8	35.5
14	1981. 8.30	18 : 54 : 53.6	121	45	24	28	0.2	5.0	180.0	23.0	31/36	17.7	31.6	43.5
15	1981.10. 5	13 : 24 : 30.5	121	45	24	39	3.6	3.4	219.2	2.7	29/37	40.5	95.5	55.7

Azim : Array to epicenter azimuth ; *T : Number of stations triggered, I : Number of stations installed in the field,

△ : Distance.

TABLE 3

EPICENTRAL PARAMETERS OF DHARAMSALA EARTHQUAKE OF APRIL 26,1985 (MB=5.5)

Date		Origin Time (GMT)			Epicentre		Focal Depth (km)	Source
		h	m	s	°N	°E		
26.4.1985	(i)	07	35	1 61	32.1	76.4	33	NEIS
	(ii)	07	35	14.86	32.20	76.27	13	Srivastava* and Chandra sekharan (1986) (Unpublished).

* Strong Motion ahd nearby stations.