Armenia

The main principles of earthquake early warning system creation around critical facilities in seismic active zone

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Before the Spitak (Armenia) 1998 destructive earthquake the territory of Armenia was constructed with buildings and structures designed for a ground acceleration of 0.1-0.2g corresponding to seismic effect with an intensity of 7-8 by scale MSK-64, according to the seismic zonation map of that time.

However, the Spitak earthquake with a magnitude M=7.0 and with intensity influence of 10 in the epicentral zone causing more than 25 thousand deaths and the destruction of most buildings and constructions in all Northern regions of Armenia, has shown that the level of seismic resistance of buildings and structures in Armenia is considerably lower than the level of seismic hazard. Taking this fact into account the new seismic zonation map of the territory of Armenia was developed in the National Survey for Seismic Protection (NSSP) RA in 1995. This map was designed by a detailed analysis of the statistic of the region's seismisity including prehistorical, historical and instrumental periods. According to this map the level of seismic hazard has been found to be I=9 with expected horizontal ground acceleration of up to 0.4g in Yerevan (the capital of Armenia).

Nearly the entire territory of Armenia is located in zones of high seismic risk. In addition, the presence of Nuclear power plant, large chemical facilities and dams creates the threat of occurring technogenic sources and flood in case of strong earthquake. However, without doubt undoubted the most dangerous zone is the territory around the Armenian nuclear power plant (ANPP).

The Armenian NPP is located in the southwest of Armenia, 28 km from the Yerevan city, capital of Armenia with 1.3 million population, 4 km from the Metsamor village and 16 km north of the Araks River.

The Armenian NPP was originally designed in 1969 to withstand seismic loads of 7 bal. After 1977 Vrancea (Romania) earthquake the seismic resistance of structures of ANPP was increased to 8 bal, and some constructions up to 9 bal. The Armenian NPP has two units of 408 mwat (gross capacity) each. Both are WWR 440-270 Soviet type reactors, which is a version of the WWER 440-230 model. The units 1 and 2 came into commercial operation in December 1976 and January 1980, respectively.

During the Armenian NPP operation time the earthquake hazard at ANNP site was revised several times:

- original site intensity, (0.1g)
- following 1977 Vrancea (Romania) earthquake re-evaluated site intensity (0.2g)
- following 1988 Spiak (Armenia) earthquake, re-evaluated seismic hazard, using the determinist approach.

Peak ground accelerations (pga) obtained for two different fractile values (50% and 84%) of those pga are 0.21g and 0.35g respectively.

The last earthquake hazard assessment at the ANPP site was performed on the basis of seismotectonic model which was scaled by Armenian NPP in 1994 [Karakhanian at al, 1994]. According to that model the nearest two faults to the NPP site are well exposed Araks active fault and Nearyerevan buried deep fault, which activity at least in holozone not revealed. Another remarkable peculiarity is the presence of dissipating seismisity zone with M=5.5 in the radius of 10 km from ANPP and the source of the strongest near-located earthquake.

The new attenuation model of ground motion for Armenia and adjacent area

Attenuation relationships play a vital role in earthquake hazard analysis and seismic design of structures. In recent years, a large number of investigations were carried out in this field and many regional relationships between earthquake, magnitude, source-station distance, local site conditions and ground motion parameters such as peak acceleration and spectral acceleration have been derived.

Based on the acceleration time histories recorded between June 1990 and September 1998 with the permanent and temporary digital strong motion network in the Caucasus and adjacent area an empirical PHA attenuation model for Caucasus area was developed [6]. This attenuation model is the first model in Caucasus region developed on the basis of accelerograms registered in Caucasus region.

The equation for larger values of peak horizontal acceleration is:

$$\log pha = 0.72 + 0.44 * M - \log R - 0.00231 * R + 0.28 * P$$

$$R = \left(D^2 + 4.5^2\right)^{1/2}$$

were pha is the peak horizontal acceleration in (cm/sec2), M is the surface-wave magnitude and D is the hypocentral distance in [km], p is 0 for 50 percentile values and 1 for 84 percentile.

The empirical attenuation relationship is considered to be valid for hypocentral distance between 4 km and 230 km and surface-wave magnitude between 4 and 7.

The predicted peak ground motion acceleration values are in good agreement with corresponding models from Western-North America. Due to the complex structure of the Caucasus the scatter and absorption of ground motion is somewhat higher than in European areas.

Using this new attenuation model the expected peak ground acceleration was estimated for ANPP site.

The performed calculations showed that expected peak ground acceleration at the ANPP site can reach 0.329g, which corresponds to accepted now PGA for ANPP site -0.35g.

Earthquake Early Warning System

It is internationally accepted that the Soviet designed nuclear power plants require seismic upgrading to various degrees (Fraas et al., 1997). The International Atomic Energy Agency (IAEA) has been carrying out assessments of seismic upgrading of the Soviet designed nuclear power plants over the past decade (Gulpinar et al., 1997). In the case where seismic upgrading by strengthening of the buildings and equipments is an expensive procedure and not feasible due to economical, political and timing reasons, an active reactor protection system based on an earthquake early warning system like alternative approaches have to be taken into consideration.

The idea of alarm system is the following: to detect the earthquake motion as early as possible near the source in order to prepare against the earthquake before seismic motion reaches the site, using difference of transmission velocities, electric communication (300.000 km/sec) and seismic waves (~3.5 km/sec). Such systems can provide pre-warning time of up to a few dozens seconds before the arrival of the destructive ground motion.

The main concept of Early Warning System was firstly introduced by J. D. Cooper, M. D. Ou in San Francisco Daily Evening Bulletin on 3rd November 1868. The report explained the concept as follows:

Since the Japanese magnet indicator has proved a failure, we are now obliged to look for some means of prognosticating this fearful convulsion, and I wish to suggest the following mode by which we may make electricity the means, perhaps, of saving thousands of lives in case of occurrence of more severe shocks than we have yet experienced. It is well known that these shocks are produced by a wave–motion of the surface of the earth, the waves radiating from a center just as they do in water when a stone is thrown in. If this center happens to be far enough from this city, we may be easily notified of the coming wave in time for all to escape from dangerous buildings before it reaches us. The rate of velocity, as observed and recorded in Dr. J. B. Trask's work in Earthquake in California from 1800 to 1864, is 61.5 (six and one fifth) miles per minute, or a little less per hour (40 miles) than the tidal wave is reported to have traveled across the ocean to this port from the Sandwich Islands or Japan.

A very simple mechanical contrivance can be arranged at various points from 10 to 100 miles from San Francisco, by which a wave of the earth high enough to do damage, will start an electric current over the wires now radiating from this city, and almost instantaneously ring an alarm bell, which should be hung in a high tower near the center of the city. This bell should be very large or peculiar sound, and known to everybody as the earthquake bell. Of course, nothing but the distant undulation of the surface of the earth should ring it. This machinery would be self-acting, and not dependent on the telegraph operators, who might not always retain presence of mind enough to telegraph at the moment, or might sound the alarm too often. As some shocks appear to come from the west, a cable might be laid to the Farallone Islands, 25 miles distant, and warning thus given of any danger from that direction (Fig. 1).

Of course there might be shocks the central force of which was too near this city to be thus protected but that is not likely to occur once in a hundred times.

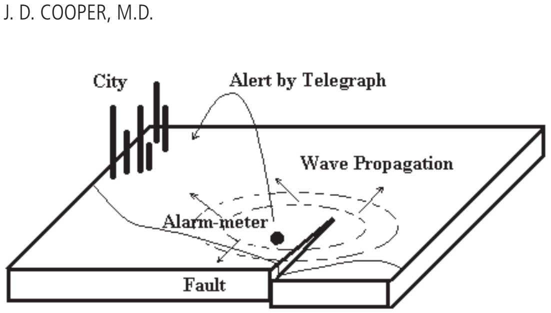


Figure 1. Concept of the Front Alarm by Dr. J. D. Cooper.

At that time, no system could realize this idea. After a century, based on this concept the several Earthquake Early Warning System were constructed in the World.

They are:

Urgent earthquake detection and alarm system (UrEDAS) in Japan.

The special feature of this system is the rapid alarm upon detecting the earthquake using information from P-wave data. By monitoring the earthquake motion of a single observation point in real time, an UrEDAS detects initial P-wave motion, estimates epicenter azimuth and magnitude, calculates epicentral distance within about three seconds after detecting P-wave. System for different railways has been in operation since 1983 (Nakamura, 1996)

Seismic Alert System (SAS) for Mexico City.

The seismic detector system has 12 digital strong motion field stations along 300km of the Mexican coast at 25 km spacing. This system consists of three units: seismic detection, telecommunications, and radio warning. The warning time in Mexico City varies between 58 and 74 seconds [2].

Seismic early warning system for Ignalina nuclear power plant.

This Seismic early warning system was installed recently in Ignalina Nuclear power Plant (INPP) in Lithuania [7]. Six seismic stations were installed in a ring centered at the plant at a distance of approximately 30 km, and the seventh station was placed in the plant. The stations are uniformly distributed as shown in Fig. 2. Each consists of three independent substations, which are approximately 500 m apart. The ground motion at each station is measured and recorded continuously by three accelerometers and seismometers. The data is transmitted via telemetry to the control center at INPP.

The time for emergency stop for RBMK reactors at Ignalina is only 2.5 seconds. The pre-warning time, provided by the seismic alarm system for the Ignalina NPP is 4 seconds. Therefore, the nuclear reaction can be stopped before the earthquake arrives.

Concept of ANPP Earthquake Early Warning System

Concept of ANPP Earthquake Early Warning System was developed on the basis of Yerevan EEWS project, considered in [1]. According to this project, the system can be based on 15 radiotelemetric control points located by circular arrangements around Yerevan city at a distance of approximately 30 km. According to this project, the warning time for Yerevan city is about 3–6.5 seconds. It is suggested that the nets of accelerographs not only be used for EWS, but also for current monitoring of weak earthquake.

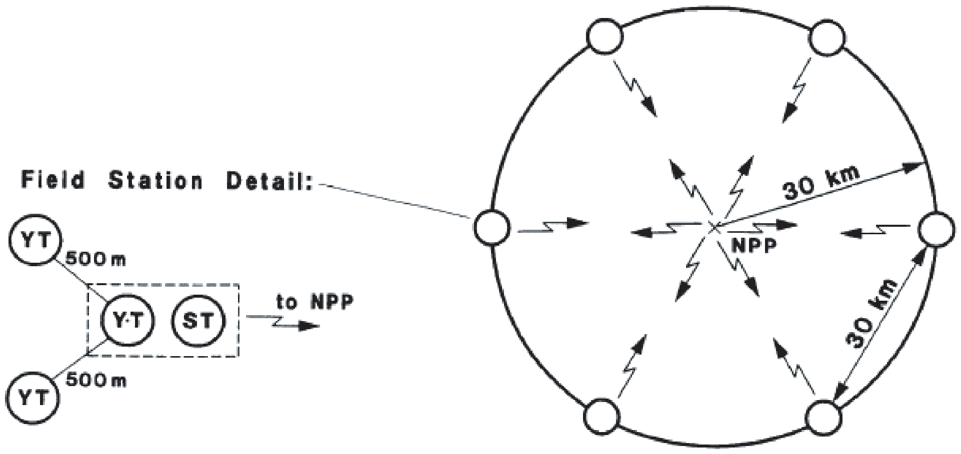


Figure 2. Layout of earthquake early warning system of Ignalina Nuclear Power Plant (INPP) (YT: accelerometer, ST: seismometer)

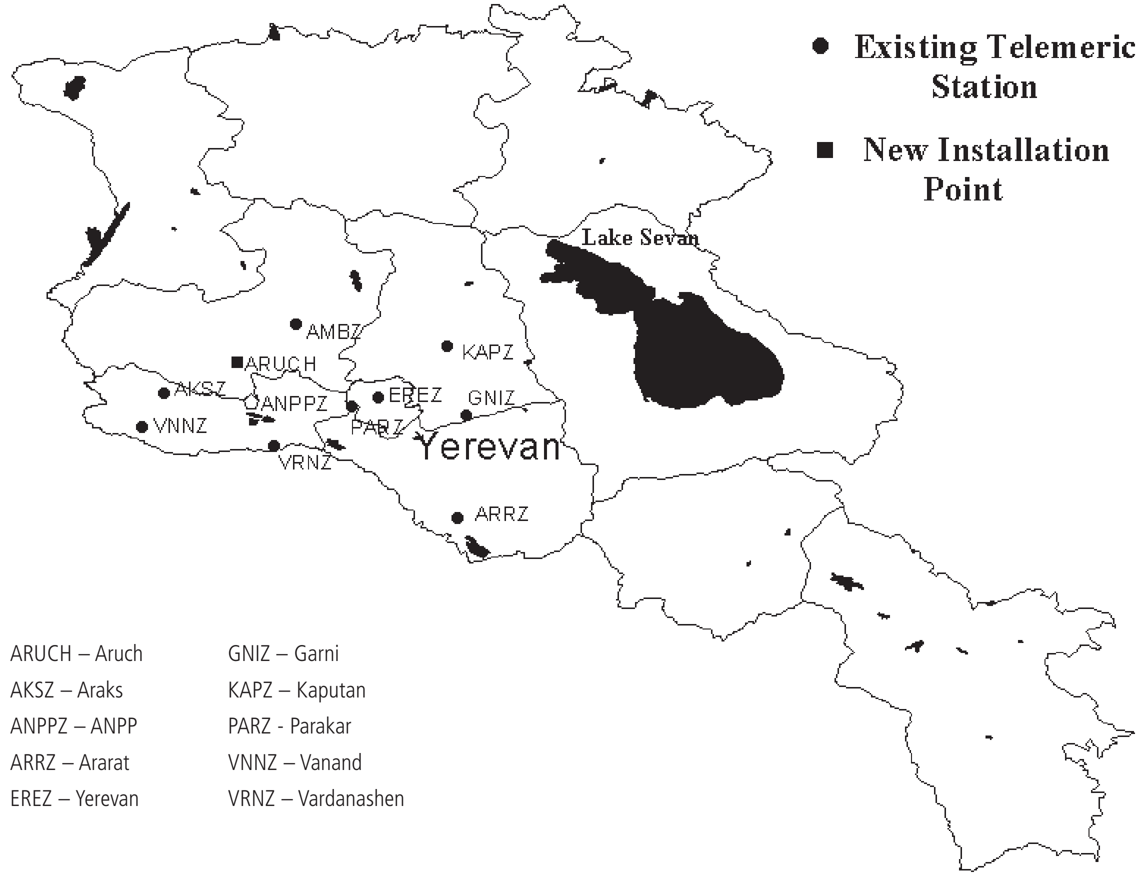
This concept can be used for other industrial facilities, such as chemical plants, life-line systems etc.

The earthquake detection is based on S-waves. In order to provide the maximum pre-warning time the seismic field stations will be installed approximately in circular arrangements around ANPP. The distance from ANPP to the field stations should be optimal. It cannot be too short, because in this case the time of the alarm will not be enough to initiate protective actions. And it also should not be too long for the following reasons: a lot of seismogeneous zones will be out of range; second, due to large perimeters of the location of the field stations in all directions.

Taking into account the location of seismogeneous zones around ANPP, as well as above mentioned arguments, it is useful to set optimal distance to 25-35 km. From this point of view, the ten field stations are required. Due to the availability of several monitoring sites around ANPP, eight of them will be located at existing NSSP telemetric stations. Another two stations will have to be new installation points (Fig. 3).

The existing monitoring system applies relay stations at several locations. These will also be used for EEWS. At the two new installation points, necessity of relay stations should be investigated. One accelerometer per station will be required. The principle of the alarm should be based on positive reaction of at least two neighboring stations in a given temporal window - in order to exclude the possibility of a false alarm in cases of equipment failures.

In a setup with ten stations, the distance between the field stations is approximately 15-20 km. The probability is extremely low that ground shaking from sources other than seismic events, e.g. from railway traffic, construction works or other man-made events, affect two stations at the same time at a distance 15-20 km.



ARUCH – Aruch
AKSZ – Araks
ANPPZ – ANPP
ARRZ – Ararat
EREZ – Yerevan
GNIZ – Garni
KAPZ – Kaputan
PARZ - Parakar
VNNZ – Vanand
VRNZ – Vardanashen

Figure 3. Map of existing telemetric stations around ANNP and new installation points

Each field station will include an accelerometers and a digitizer (Fig. 4).

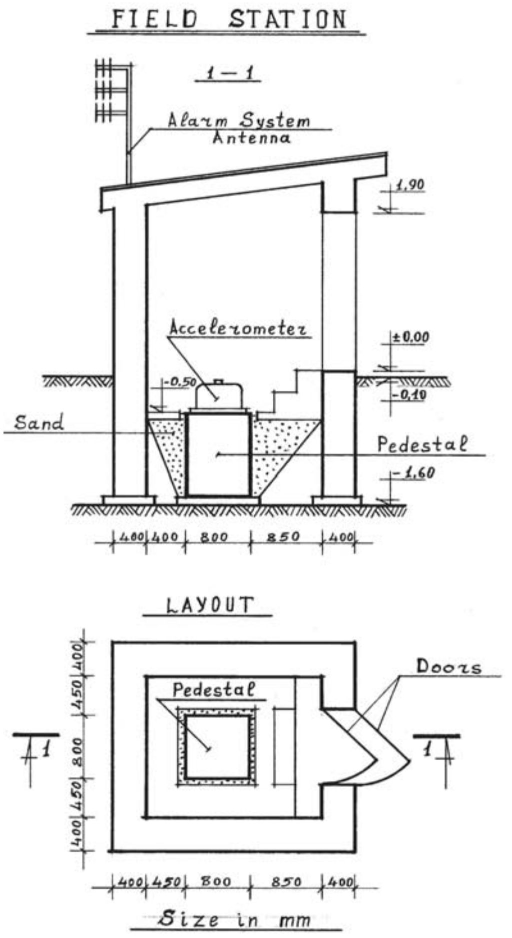


Figure 4. Simple scheme of investigation station

The digital signal will lead to the differentiation software processor. The special software will differentiate each event on seismic event and non-seismic event. One factor in this context is the frequency. Above 10Hz, a non seismic event is indicated, at lower frequencies it may be an earthquake. For seismic events the frequency peak must be between 2 to 10 Hz. The Fast Fourier Transformation (FFT) provides valuable information about frequency content of a seismic event. If the FFT shows a dominant frequency within the predetermined bandwidth, a switch is set to FFT: Yes.

Seismic events with frequencies beyond 10Hz are possible. However, these are minor events, which do not cause any problems for the nuclear power plant.

The second factor is Cumulative Absolute Velocity (CAV). The CAV algorithm is applied to the seismic data, which is filtered between 2 to 10Hz. If, within 1 second, the data exceeds a predefined level, the acceleration value is multiplied by 1 second (resulting in a velocity) and added to the CAV sum. If CAV exceeds a predetermined value, a switch is set to CAV: Yes.

For this purpose, the Seismic Alarm System Software, SEISDIFF, which was conceptually developed by EWE-GeoSys, should be useful. The time required by SEISDIFF to detect a relevant Seismic event is 1second following the arrival of the S-wave at the field station. Since the event is checked from different points of view, the reliability of the alarm is improved and false alarms are eliminated. This increases the reliability of the Seismic Alarm System.

As to threshold, acceleration values above which the installed accelerographs at control points must respond should be estimated taking into account that at ANPP site acceleration should be more than 0.1g. By the studying the seismic waves attenuation with the distance, as well as ground condition at field points we estimated the threshold value of instruments on control points. It is equal to 0.15g.

Finally, about the mean time of the alarm. The simple estimation including the configuration of EEWS and considering velocity of seismic shear waves of about 3.5 km/sec show that the earthquake will be detected 7-10 seconds before the arrival at the plant site. Differentiation of each event to seismic event and non-seismic event requires 2 seconds, also 1-2 seconds will be lost on receiving the alarm signals from the two neighboring field stations. Therefore the pre-warning time should be 3-7 seconds.

Application to WWER-type reactors

The WWER Soviet built nuclear reactor is pressurized water reactor. The emergency shutdown of the WWER nuclear reactor is characterized by an increased insertion time of the control rods up to 12 seconds. The pre-warning time provided by AEEWS may not be sufficient for the control rods to reach their lower position in the reactor core. But it will be sufficient to issue control rods insertion signal and to release them from the positioning mechanism. The control rods may not have reached the lower position in the reactor core before the destructive earthquake arrives at the site, but the dropping down of the rods is at least in progress.

Conclusion

The concept of Earthquake Early Warning System for ANPP is developed. In this system, the earthquake detection is based on S-waves. The seismic field stations will be installed approximately in circular arrangements around ANPP. The pre-warning time provided by AEEWS is about 3-7seconds, that may not be sufficient for the WWER type nuclear reactor control rods to reach their lower position in the reactor core, but it will be sufficient to issue control rods insertion signal and to release them from the positioning mechanism, and dropping down of the rods will be at least in progress. The principle of the alarm should be based on positive reaction of at least two neighboring stations in a given temporal window- in order to exclude the possibility of a false alarm in case of instrument failures. More than one algorithm for differentiation between seismic and non–seismic events will be used. This concept also can be used for other industrial facilities, such as chemical plants, life-line systems and others.

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