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Seismic Monitoring of Nuclear Power Plants (NPPs)

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ABSTRACT: According to IAEA safety guides and US-NRC regulatory guides, seismic hazards shall be evaluated for each NPP. Likewise the seismic and geologic design basis requirements (such as Safe Shut-down Earthquake & Operating Basis Earthquake) must be determined for such facilities. Determination of the SSE and the OBE should be based on the identification of tectonic provinces or active geologic structures with which earthquake activity in the region can be associated. The design vibratory ground motion for the SSE and OBE should then be determined by assessing and monitoring the effects at the site with the identified provinces or structures.

To carry out this purpose, a specific seismic site network and a series of accelerographs were recently installed at a new NPP under construction in Iran in order to record micro-earthquakes. The local wireless seismic network consists of five seismic stations encircling NPP centre at a radial distance of approximately 30 km of which the fifth station was installed at NPP's site centre. Each station includes a broadband seismometer that measures all ground motions and the data is transmitted via telemetry to the control centre at NPP site. Three triaxial time-history accelerographs are also provided on the free-field and in the two depths of 100 and 150 meter of a geotechnical borehole to measure strong ground motions. In the future, three other ones will be installed in three elevations of the concrete containment structure, and two others of this type will be established in two elevations of each independent Seismic Category I structures.

This paper discusses the site selection, operation and utilization of seismographer stations for monitoring of seismic sources and tectonic structures and other instrumentations that required for seismic monitoring of NPPs.

1. INTRODUCTION

Iran plateau is one of the most active regions in the Alpine-Himalaya Orogenic region with respect to earthquakes and tectonic motions. The site of the first domestic Nuclear Power Plant (IR360), in Darkhovin region in the southwest of Khuzestan plain is located on the Arabian platform beside of Zagros Seismotectonic province. Young active Zagros thrust-fold-belt, accommodates part of the convergence between Arabia and Eurasia and settles in north-northwest of the structure. This paper describes the necessity of deploying suitable seismic instrumentations for immediately recording micro earthquakes and soil response that is acceptable to the IAEA and NRC standards and regulations (10 CFR Parts 50). It is also necessary to determine whether the plant shutdown is required during operation. This decision will be modeled by comparing the recorded data against OBE exceedance criteria and by evaluating the results of the plant walk down inspections that take place within 8 hours of the event (Reg. Guide 1.208, 1.165). Therefore, micro earthquakes monitoring and those studies are unavoidable in order to estimate the location, geometry and size of slip on faults, especially before and after of NPPD construction (Reg. Guide 1.70). According to this purpose, the local network with 5 seismograph stations at around the IR360 was made. In future, for the measuring of maximum seismic response in Category I structures, the accelerograms will be located on the foundation level and on two elevations in the structures (Reg. Guide 1.12).

2. TECTONIC SETTING

The site is located in the southwest Khuzestan plain on Arabian platform beside of Zagros seismotectonic province. The studied region has been affected by tectonical motions in Zagros Seismotectonic province that its characters are described as the following.
Mirzaei and et al (Mirzaei et al, 1998) by paying attention to the tectonical behaviour and seismicity pattern, have divided Iran into five main seismotectonic provinces; 1. Alborz-Azarbayjan, 2. Kopeh Dagh, 3. Zagros, 4. Central Iran and eastern Iran and 5. Makran (Figure1).

3. ZAGROS SIESMOTECTONIC PROVINCE

Zagros is situated at northern side of Arabian plateau on Precambrian metamorphic basement. From structural point of view, its configuration was according to the steady converging movement of Arabian plate in the southwest and Central Iran micro plate in the northeast which results from the continent-continent collision between the Arabian margin and the Eurasian plate (Alavi, 1994 and Berberian, 1995).

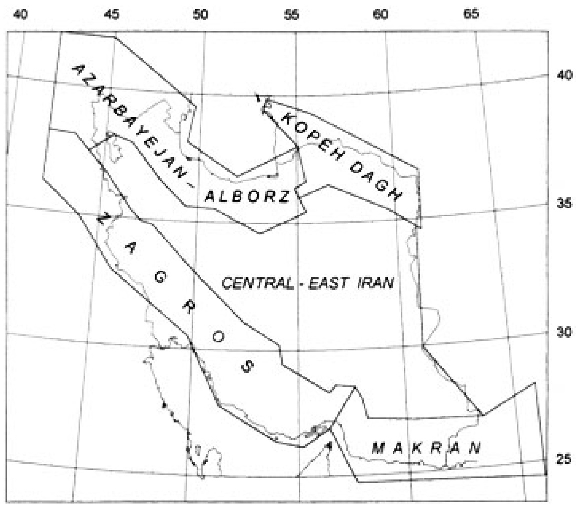

Figure 1. The seismotectonic provinces of Iran
(Mirzaei et al, 1998,)

The Zagros contains a thick and almost continuous sequences shelf sediments deposited on the 1–2 km thick infra-Cambrian Hormoz Salt formation. The sediments of Paleozoic to Late Tertiary age are believed to be separated from the Precambrian metamorphic basement by this Hormoz salt layer that it's highly affected to the Zogros tectonic region. Over 50% of the earthquakes that occurs in Iran take place in the Zagros. Most earthquakes are thought to occur on ‘blind active thrust faults’ (Berberian, 1995) that do not reach to the surface. However earthquakes in collision region can locate shallow (the focal depth less than 70 km) and disperse. Studies by Jackson & Fitch (Jackson et al, 1981) show that all of apparently deep earthquakes in the Zagros, had been of small magnitude, were not well recorded and didn’t have suitable quality for depth determination.

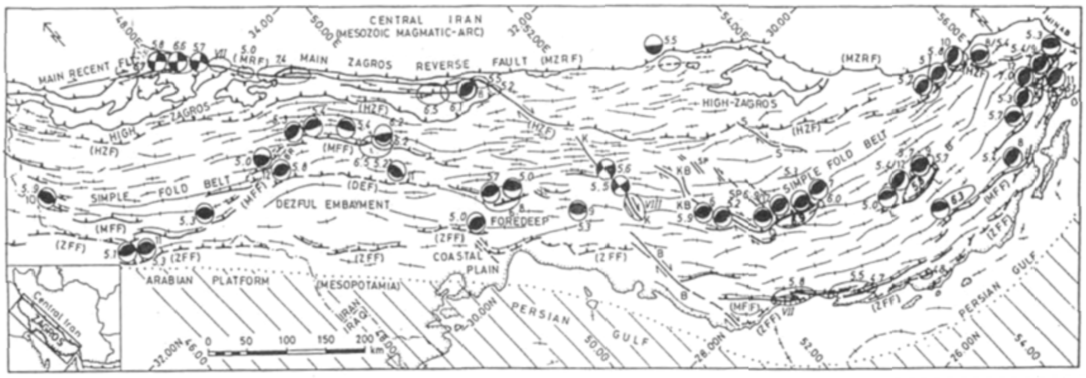

Figure 2. Active faults map, focal mechanisms of earthquakes and maximum ruined are of Zagros ruin able earthquake (Berberian, 1995).

The large earthquakes in Zagros occur along the northwest Zagros margin on current faulted sections with northwest- southeast trend with right lateral strike-slip fault mechanisms (for example: The 1909 Silakhor earthquake with magnitude Ms= 7.4 occurred in Silakhor plain, on January 23, 1909. The event occurred on Dorud fault that is the biggest recorded event in Zagros).

4. EARTHQUAKE SOURCES

Earthquake sources in Darkhovein site region is illustrated in Figure 3. The figure shows, the nearest source to Darkhovein site is Ahvaz earthquake source which can cause earthquakes with magnitude 6.5-7.0. The least distance to this source is 64 km to the site. We can point on the other features such as Darkhovein anticline, Khoramshahr anticline and also probability faults (Zagros, Karun and Darkhovein lineaments) which are presented in Figure 4.

Figure 3. Earthquake sources around Darkhovein (source locations is based on Mirzaei et al, 1998)

5. SEISMICITY

The location of historical earthquakes (before 1900) and the first instrumental period earthquakes (1900-1973) are presented in Figure 4. The nearest historical event to the site is historical earthquake at 840 A.D. with magnitude 6.5 around Ahwaz (Ambraseys and Melville, 1982) and its epicenter has a 77km distance from the site.

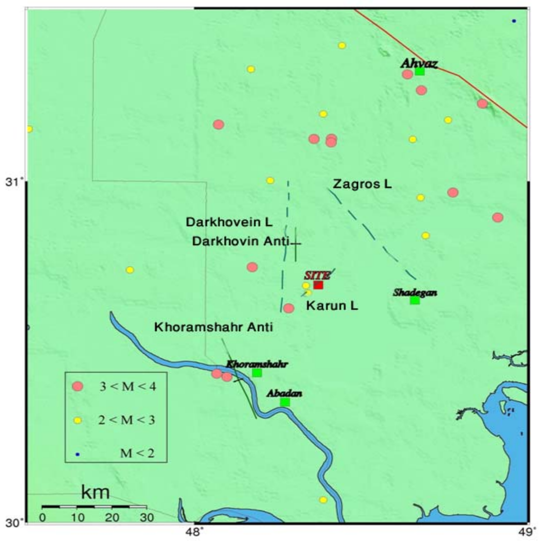

Figure 4. The lineaments around Darkhovein and recorded earthquakes

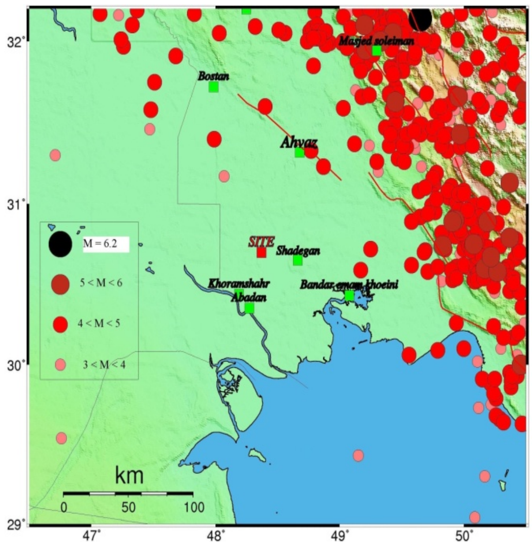

Figure 5. Historical earthquakes instrumental earthquakes (before1973) around Darkhovein

The occurred earthquakes around the site are presented in the picture 6 on the basis of the USGS catalogue from 1973 to January 1, 2009. The largest earthquake in this picture is Ms= 6.2 at 1978, in 200 km distance, and the nearest earthquake to the site is earthquake with magnitude Mb=3.7 in 2007, in a 59 km distance. There are two earthquakes with magnitude of 4 and 4.4 that attract the attention around the historical earthquake epicenter of Ahwaz (Figures 5 and 6). In the bulletin of International Seismology Centre (ISC), there is earthquake with magnitude Mb=4.6, in 14 km of the site at 1981/10/27 that is not indicated in the bulletin of USGS. It is necessary to note, that the Kermanshah station (KER) has determined the location which has a distance of 360 km with azimuthally gap 227. Therefore the location and type of this earthquake has low reliability.

6. THE SEISMOGHRAPH NETWORK OF DARKHOVIN

There is an old local seismograph network with five stations around the site, which are used from one axial time-history seismograms to detect earth moment. Seismograms are 4 biaxial and at one tri-axial, that one of them is always vertical in all the stations. The location of stations are shown in Figure 7 with the triangular shapes and the new suggested location of stations have been shown in the black circular forms from procurer, but, the numbered circular forms suggested by this paper authors on basis of existence source earthquakes and showed seismicity. In by paying attention to the sensitivity of new seismographs and also to the unsuitable location of old seismographs which mostly are located in the buildings yard or area with heavy traffic, the cost payment and upgrading of this network will not be suitable if the installation and operation of new equipments are established at those old locations. Therefore, the new optimum site location is an essential and necessary task. One important problem that was not noticed at the old network is to uncover the Darkhovein lineament. The fifth station is introduced to remove this problem at the old array. By paying attention to the converging of the Darkhovein and Zagros lineaments in the north of the site, another station should be added, if possible, around Rahmanyeh, Nesareh, Dorsyeh and Taban villages. The approximate location of this suggested station is presented with number 6 in the picture 7.

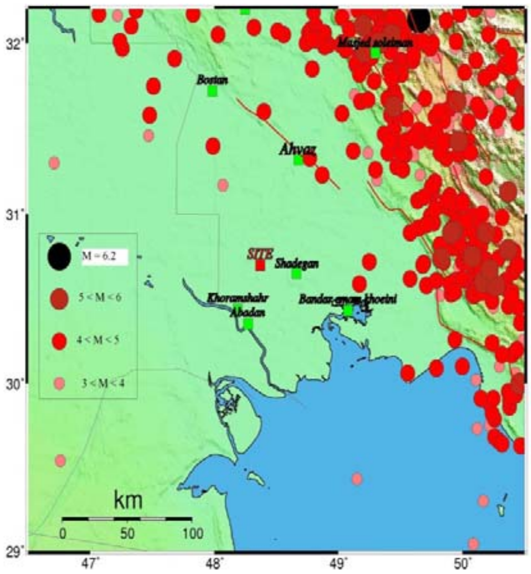

Figure 6. The instrumental earthquakes around the site (1973-2009)

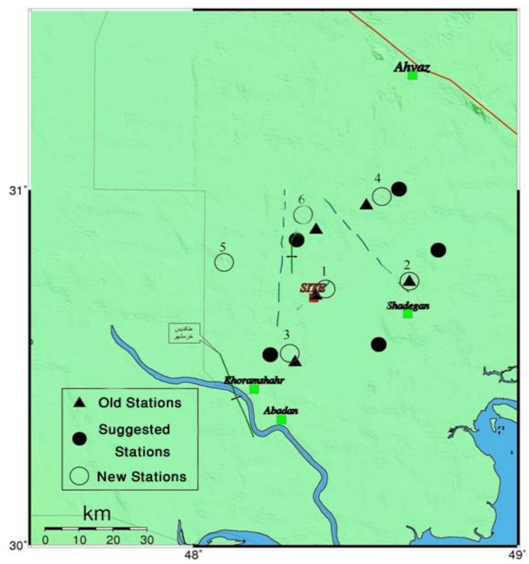

Figure 7. The location of old stations and new stations

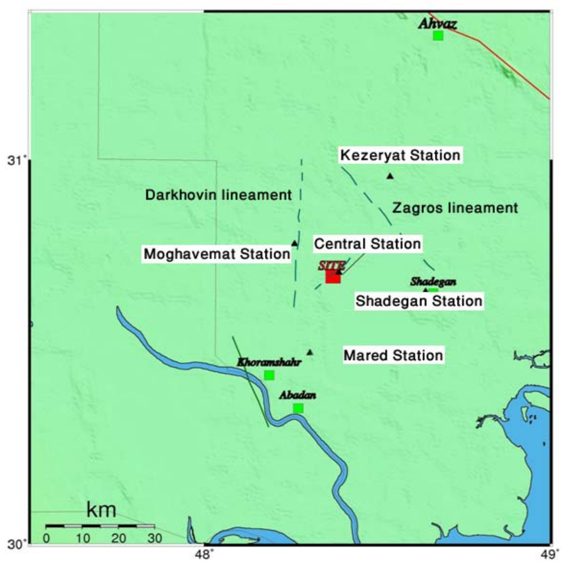

Figure 8. The selected stations array of Darkhovein network

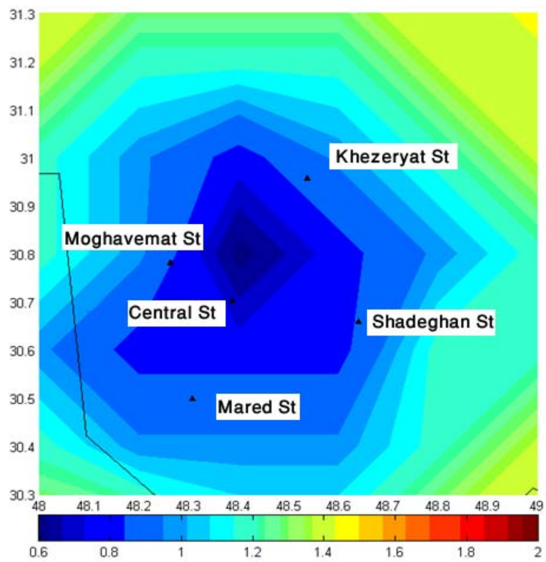

Figure 9. The result of modelling to threshold of complete record around

The Darkhovein site and districts around it was visited and the field was studied for building the new stations. In this visit, after attention to the local noise, the best feasible location was selected. In this study, it is tried that selected locations, such as first suggestion, cover all the seismic sources around the site, up to the smallest vibrations to be recorded and located. In Figure 9, the location of selected stations and array of seismograph network are presented after studying all parameters. By considering one of these points, modeling reveals that threshold of complete record around the site area is under magnitude 1 (about 0.8). Result of modeling is in Figure 9.

6.1 *The Khezeryat station*

This station is located near Khezeryat Bavi village which has a low population in northeast of the site in a distance 30km from it. Distance of the nearest building to station is a little more than 50 meters. In this station the most important factor to makes noise is the road between Ahwaz-Khoramshahr. The distance of this road to station is a little more than 800 meters and also far away from the sugarcane farmlands about 120 meters away. For noise reducing purpose, the location of sensor will make more depth as possible.

6.2 *The Mared station*

This station is located in southwest of Darkhovein site and about 25km far from the site. In this station the most important factor is the noise from the Karun River about 700 km far from the station, and also rural road with very low traffic about 100 meters far from. There is one asphalt factory that its materials are brought from another place. Therefore, there is not any mining activity and its noise is tolerable. In spite of this, for noise reduction purposes, the location of sensor, if possible, should be of more depth. At this point, transmission connection won't have any difficulties.

6.3 *The Shadegan station*

Shadegan station is located in the east of Darkhovein site and is about 25km far from the site. By paying attention to the environmental limitations, it is believed that the best location is recognized to be at the enclosure of meteorological station. In this station the most important factor is the noise from the main road of Shadegan town about 180 km far from the station. The employee and location of meteorological station is another source of noise. Therefore, it is tried to locate the site at a low commuting location. In spite of this, for noise reduction purposes, the location of sensor, if possible, should be of more depth. At this point, as previously indicated, transmission connection won't have any difficulties.

6.4 *The Moghavemat station*

This station is located in northwest of Darkhovein site and is about 15km far from the site. At first, in accordance with existence of Darkhovein lineaments, it was tried to locate near the west of this lineament as far as possible. The dispatched group after reaching the borders, based on the existing difficulties, decided to select the best region before reaching the buffer zone. The best selected region is near the Petrol Co guard. The most important factor of noise in this station is the transportation in the special road of Petrol Co, which is located 70 meters far from the station. The situation of Moghavemat station on the satellite image is clear. At this point, as previously indicated, transmission connection won't have any difficulties.

6.5 *The Central station*

Considering that the final site layout of the site was not available, selecting the best location for the Central station is hard. Whereas the station, according to the existence of earthquake source can play a fundamental role due attention must be paid for determining the location of local earthquakes. Therefore, we suggest the building of the site to be in a place which has the least concentration of constructions in its vicinity. Regarding the low distance of the station from the centre of network and district topography of the site, transmission sight is available completely.

7. ACCELEROGRAPH STATIONs

According to RG 1.12, trusting the accelerogram of earth strong motion depends on suitable installation, providing suitable environmental stations for working and regular protection. The free-field sensors are located and installed so that they record the motion of the ground surface and so that the effects associated with surface features, buildings, and components on the recorded ground motion will be insignificant. Since the building hasn't been built yet, the installations of two accelerographs for getting natural soil period and soil earthquakes reply are performed on free field and in the down hole. These facilities are located under reactor and down hole beside reactor building and in a 120 meters depth which is placed between the soil surface and basement rock to get exact earthquake reply from soil thickness of the region. In free field state evaluation the earthquake reply in the basic design will be inspected and compared with the loading state.

8. REFERENCES:

A Performance – Based Approach to Define the Site – *Specific Earthquake Ground Motion*, March 2007, US NRC Regulatory Guide 1.208.

Alavi, M., 1994, *Tectonics of the Zagros orogenic belt of Iran: new data and interpretations*, Tectono-physics, 229, 211-238.

Ambraseys, N. N. and Melville, C. P., 1982, *A history of Persian earthquakes*, Cambridge University press, Cambridge, 219 pp.

Berberian, M., 1995, Master "*blind*" *thrust faults hidden under the Zagros folds: active basement tectonics and surface morphotectonics*, Tectonophysics, 241, 193-224.

Geologic and Seismic Criteria, US NRC, 10 CFR Parts 50, Appendix S, *Earthquake Engineering Criteria for Nuclear Power Plants* ,2007. Aug. 15, 1991

Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion, US NRC Regulatory Guide 1.165.

Jackson, J. A., Fitch, T. J. and McKenzi, D. P., 1981, *Active thrusting and the evolution of the Zagros fold belt*, in: McClay, K. R. and Price, N. J. (eds.), *Thrust and Nappe Tectonics*, Geol. Soc. Spec. Pub., 9, 371-379.

Mirzaei, N., Gao, M. and Chen, Y. T., 1998, *Seismic source regionalization for seismic zoning of Iran: major seismotectonic provinces*, J. Earthq. Pred. Res., 7, 465- 495.

Nuclare Power Plant Instrumentation for Earthquakes, US NRC, Regulatory Guide 1.12.

Standard Format and Content of SAR for NPP, Rev 3. November 1978, US NRC Regulatory Guide 1.70.