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SEISMIC HAZARD ANALYSIS OF ZARAND CITY USING AHP-GIS

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EXTENDED ABSTRACT

Questo studio presenta la carta di pericolosità sismica della città di Zarand in Iran, considerando fenomeni di rottura. La carta sismotettonica di Zarand è stata realizzata utilizzando i terremoti e le relative sorgenti avvenuti entro un'area individuata della carta geologica di Zarand alla scala di 1:100.000. La città di Zarand è vicina a una faglia attiva, conosciuta come faglia di Kuhbanan localizzata a Nord Est della città. Il giorno 21 del mese di Dicembre del 1977 l'area è stata colpita da un terremoto di magnitudo 6.2 che ha distrutto completamente 3 città e provocato 521 vittime. Il terremoto con magnitudo maggiore che ha colpito l'area è stato quello avvenuto nel 2005, con magnitudo momento 6.4 ed epicentro sito nella zona della faglia di Kuhbanan. I terremoti disponibili sono stati suddivisi in due categorie: una include eventi di magnitudo momento 5 o superiore, quindi terremoti in grado di provocare danni, l'altra include gli eventi rimanenti, quindi di minore intensità. La frequenza di terremoti con magnitudo 6 è limitata, terremoti di magnitudo media o bassa sono maggiormente frequenti in un area compresa tra 30.40° e 30.50° di latitudine e tra 56.40° e 57° di longitudine. Le caratteristiche geologiche di sito influiscono sensibilmente sull'intensità dello scuotimento sismico al suolo. Questa è la ragione per cui si evidenziano edifici molto danneggiati molto vicini ad edifici di simili caratteristiche costruttive che non hanno subito gravi danneggiamenti. Le argilliti delle Formazioni di Zagun, Sorkh e di Sardar agiscono come fattore di riduzione della velocità delle onde sismiche dei terremoti e della loro energia, la frequenza delle onde aumenta in queste rocce, questi fattori possono indurre la distruzione di strutture. Le Formazioni di Lalun, Espahk, Jamal e Bahram mostrano comportamento fragile a causa della loro competenza e possono essere interessate da crolli durante i terremoti. L'attività sismica di una regione può essere caratterizzata in termini di rapporto frequenza-magnitudo Gutenberg–Richter

$$\log10\ (N) = a - b^*Mw$$

dove N è il numero di sismi caratterizzati da magnitudo Mw uguale o maggiore di un prefissato valore, i parametri a, b sono dipendenti dalla sismicità della regione. Il modo più semplice per ottenerli è con la tecnica della regressione dei minimi quadrati, tuttavia a causa dell'insufficienza del database, questa procedura potrebbe portare a risultati errati. I terremoti utilizzati coprono un arco temporale dal 1900 al 2016. La legge della ricorrenza Gutenberg–Richter è valida per magnitudo da Mo pari a 4.0 fino a magnitudo Mmax pari a 8.0. L'analisi di pericolosità sismica effettuata con approccio probabilistico indica, per l'area di studio, una probabilità di accadimento di un terremoto di magnitudo maggiore di 6.5 nei prossimi 20 anni pari al 100%. Sulla base della carta di zonazione della pericolosità sismica, costruita sulla base di dati storici e strumentali, sono state valutate distanza epicentrale, magnitudo e le distanze dalla faglia; il livello di rischio nella regione aumenta nelle aree centrale, settentrionale e nord-orientale. Inoltre si evidenzia come la zonazione della pericolosità sismica nella regione, realizzata attraverso un approccio Analytic Hierarchy Process (AHP) in ambiente ArcGIS 10.2, è dipendente dalla distanza dalla faglia, dalla magnitudo del terremoto, dalla distanza epicentrale, dalla profondità del terremoto e dalla litologia. I risultati della carta di zonazione gerarchica realizzata con approccio AHP mostrano che il 24.22% dell'area studiata è a rischio molto alto. Le aree ad alto rischio sono individuate nella parte centrale, settentrionale e orientale dell'area, i metodi analitici e probabilistici indicano che Zarand è una delle unità sismotettoniche più attive in Iran e che vicino questa città sono presenti molte faglie. Il metodo probabilistico indica che un terremoto con magnitudo di 7 nei prossimi 30 anni ha probabilità di accedere del 99.99 %. In accordo con la carta di zonazione della pericolosità sismica e la frequenza degli eventi sismici l'area è caratterizzata da conclamata pericolosità sismica. La percentuale maggiore di pericolosità sismica dell'area di studio si trova nella zona con alto rischio con una copertura pari al 35.43% dell'area di studio, mentre la zona con rischio molto alto copre un'area del 24.29%.

ABSTRACT

This paper presents a detailed study about the seismic pattern of Zarand County in Kerman province that is an area with a high risk of earthquakes in Iran.

The population of the Zarand County is about 120000. There are numerous active faults in the region and the area has been hit by several strong earthquakes, two of which were most deadly during the last half-century.In this research, the seismotectonics and seismic hazard was evaluated by probabilistic and analytical methods in 1:100000 scale geological map of the Zarand. Seismic risk analysis using the Gutenberg-Richter law predicted the probability for an earthquake with a magnitude of 6.5 on the Richter scale in the area within the next 40 years, 100 percent. Based on the results, Zarand City is considered as a medium and high earthquake risk area. The highest percentage of earthquake hazard is located in the central and north and northeastern regions of Zarand's geological map. In this map, the area with a high risk and very high risk is 35.43% and 24.22% respectively.

KEYWORDS: *seismic hazard, AHP, Zarand city, GIS, central Iran*

INTRODUCTION

Four major tectonic plates (Arabia, Eurasia, India, and Africa) and one smaller tectonic block (Anatolia) are responsible for seismicity and tectonics in the Middle East and surrounding region. As Iran is located between the Arabian and Eurasian plates, which are converging at a rate of about 24 mm yr–1, the principal style of deformation within Iran is shortening with common reverse faulting earthquakes (ROUHOLLAHI *et alii*, 2012). Central Iran is characterized by scattered seismic activity with large magnitude earthquakes, long recurrence periods and seismic gaps along several Quaternary faults. The earthquakes in the zone are generally shallow and are usually associated with surface faulting (BERBERIAN, 1979). Quantifying the level of ground shaking which can be expected in a given region within a given time is the main aim of any seismic hazard assessment. This is naturally dependent on the seismic activity in the region, but also on factors such as the time elapsed since the previous large earthquake and the distance to large faults. The present study concerns the seismotectonic analysis of large and small earthquakes that took place in Zarand (Fig. 1) in central Iranian block, over a period of 40 years from 1974 to 2016. The city of Zarand with an area of 11521 square kilometers, is located at 56˚ 34' east longitude and 30˚ 49' north latitude and average height 1660 meters above sea level.

Zarand is close to an active fault, known as the Kuhbanan fault in the north east section. The fault trend is northwest-southeast and its length is 160 km. Zarand has been hit by several quakes in the past 70 years, with the oldest recorded

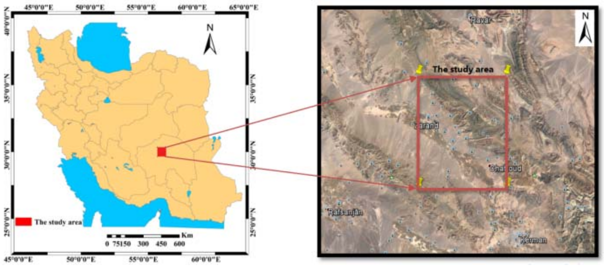

Fig. 1 - Map showing the location of the study area, rectangle shows the position of the study area

one going back to 1933. On December 21, 1977, the area was hit by a 6.2-magnitude earthquake leaving 521 dead and 3 villages completely destroyed. On December 26, 2003, there was another devastating earthquake in Bam, 200 km southwest of Zarand, which is in the same province. The 2005 Zarand earthquake affected several villages in the Kerman province of Iran on February 22. The shock measured 6.4 on the moment magnitude scale and had a maximum Mercalli intensity of VIII (Severe). The epicentre, located at the Kuhbanan fault zone ruptured an intramountain reverse fault striking EW and dipping to the north (TALEBIAN *et alii*, 2006).

By investigating and identifying the tectonic system and faulting in different areas, determining and categorizing the faults and zoning of the area is very important. It is based on the magnitude of the occurrence of earthquake or risk to reducing damage in future probable earthquakes. Considering the importance of the issue, many studies have been carried out today including studies of HOSSEINI *et alii*, 2014; ARTIKOV *et alii*, 2016; PELA´EZ *et alii*, 2005; BABIKER *et alii*, 2015; SHAO *et alii*, 2016; TAMIMA & CHOUINARD, 2016; SAFARI *et alii,* 2010; LIU *et alii*, 2016; EZZELARAB *et alii*, 2016; FRIGERIO *et alii*, 2016 and MUELLER *et alii*, 2015. The purpose of this study is to identify the faults in terms of seismicity, and to determine and identify the tectonic condition of the Zarand area. Finally, by providing seismic data bank, the seismic zoning of the earthquake risk is zoned. To this end, the Gothenburg-Richter method and the Analytic Hierarchical Process (AHP) method were used. In the process of the Analytic Hierarchical Process, complex problems were examined based on their interactions and they were transformed into simple solutions for solving the problems. AHP can be used when decision-making with multiple competing choices and decision criteria can be used, which can be quantitative and qualitative. The basis of this decision is the decision on the paired comparisons.

RESEARCH METHODOLOGY

The methodology of this research includes preliminary studies for gathering necessary information, seismic analysis of the area of studies, software researches, analysis and final conclusions. In a preliminary study with a targeted study of some of the resources available in this field, tried to provide basic information for the next steps. The earthquake data was provided by the end of 2016. In order to prepare the seismotectonic map of the area, the geological 1: 100000 map of Zarand city was used in the ArcGIS10.2 software environment, then the faults identified on the geological map were determined in an information layer in ArcGIS10.2 software. Satellite images were also used to investigate faults in the area. The location of all earthquakes in the region was identified and recorded by the software. Ultimately, the position of all faults and earthquakes in relation to each other was presented in the map. Seismic analysis of the area was carried out using the Gothenburg-Richter preparatory method (GUTENBERG & RICHTER, 1956). For earthquake hazard zoning map of Zarand, the criteria for distance from the fault lines, earthquake magnitude, earthquake depth, and epicenter was used. Geological maps sheet at 1: 100000 was used to provide map of distance from faults and lithology. For the preparation of earthquake magnitude map (MS), earthquake depth and epicenter, seismic data bank was used, and earthquakes information in the ArcGIS10.2 software converted to a vector file. Then, using the interpolation function, earthquake depth and earthquake magnitude map were prepared by Inverse Distance Weighted (IDW) method. All data layers were digitized using the ArcGIS10.2 software. Using a hierarchical analysis method (AHP), the weight of each criterion and its criteria were determined. Finally, the combination of weighted information layers in ArcGIS10.2 software environment was performed using the Raster Calculator method (Fig 2).

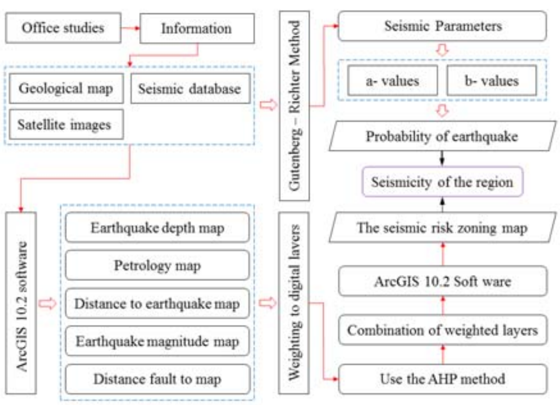

Fig. 2 - Method of doing this in this study

THE TECTONIC FRAMWORK OF THE STUDY AREA

The study area is part of the central Iran's tectonic zone, which can be distinguished from related structural signs such as moderate-to-severe folds, reversals, alternate motions, or rotation of blocks. Most of their effects on the prevailing conditions on sedimentation basins are observed in the form of large changes in sedimentary facies in short-range distances, sedimentation defects and discontinuities and abrupt collapse of buildings. With the exception of Quaternary deposits, the rest of the sediments have been severely folded in all history of geology, and numerous cases of repeated structures, abundant repercussions, or even the surface of fold to faults progression in the area is there.Different degrees of folding have been observed from gentle to severe, and even reversed, in many parts of the region, but at present, as a result of major Alpine orogeny, and in particular the late Cenozoic movements, the main folds axis of the area are showing northwest - south east direction (VAHDATTI DANESHMAND, 1995).

Faults movement is the most important factor in creating earthquakes in each region. Identifying and determining the length, profile and ability of seismicity of faults is one of the ways to estimate the risk of a study area. The most important known fault in the study area is Kuhbanan fault. Kuhbanan fault is one of the major faults in Kerman province, and the length of this fault is estimated to be 900 km and the general trend is northwest - southeast. In the north of Kuhbanan (north of Kerman), this fault separates rock heights from young alluvial deposits. Kuhbanan fault has cut off the Quaternary sediments and can be considered as an active fault that is associated with earthquakes and faults.

Among the historical and catastrophic earthquakes caused by Kuhbnan fault, the earthquakes of 1933 ZARAND-BEHABAD, 1976 GAZIK and 2004 HOTKAN & DAHUIEH can be mentioned (TAVAKOLI, 2008).

THE TECTONIC PROCESS OF THE REGION

Certainly, in order to study the risk of earthquakes in different regions and to provide applications for urban and rural expansion, all information can't be cited from small scale maps. The simplest form of seismic risk assessment is the detailed study of the process, distribution, and frequency of earthquake events in the area under study and the identification of areas that have been damaged by earthquakes a long time ago. Earthquakes occur mainly in the region's active faults, in other words, faults have the most potential for earthquakes. Therefore, identifying the exact location of the major faults and minor faults in the regions has the most assistance in identifying the hazardous areas of the earthquake.

In this research, considering the location of the region in the active and important area of Iran, all the faults (active faults, faults with activity potential and subtle-activity faults) are actively considered, and in the analysis are considered.

As shown in Fig. 3, the direction of structural features of the region is almost northwest - the southeast.

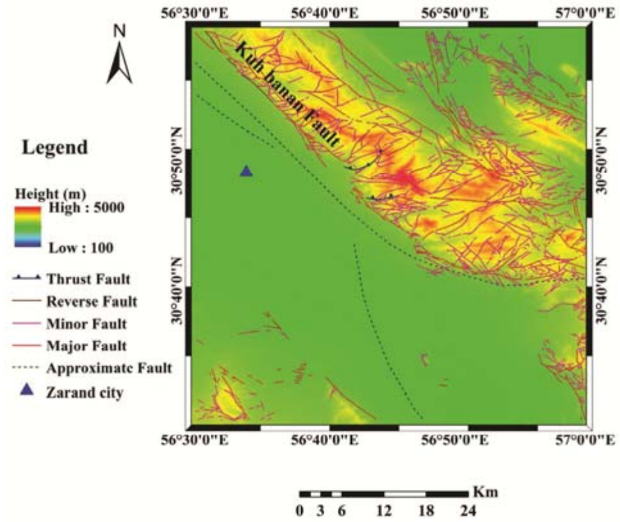

Fig. 3 - The map of major and minor faults (GSI 1:100,000 Geological maps), earthquake magnitude (USGS) in the Zarand area

Seismic Data Uniformity

Various units have been used to describe earthquake magnitudes. In order for gathering and compiling catalogs, it is necessary by proper order of magnitude conversion to obtain a uniform expression of magnitude (for example, the magnitude of surface waves, MS). Therefore, to achieve this, the relationship between the moment magnitudes with other HEATON & HARTZELL magnitudes (1988) has been used.

$$Mw = 0.78130\ Mb + 1.5175 \quad (1)$$

$$Mw = 1.0209\ M + 1.0436 \quad (2)$$

$$Mw = 0.6960\ M + 1.7738 \quad (3)$$

Earthquake Data

The earthquake database refers to the information, profile and number of earthquakes occurring and recorded for different regions. Earthquakes at different time intervals are classified by the historical and instrumental seismicity records. The main references used for historical seismic data in this study are the history of Iran's earthquakes (AMBRASEYS & MELVILLE, 1982), Seismicity of Iran (AMBRASEYS & MOINFAR, 1973) and the first earthquake catalog of Iran (BERBERIAN, 1995). Also, in this study, seismic data were recorded from 1900 to 2016 (ISC, 2016 and IIEES, 2016).

Seismotectonic of Study Area

Since earthquakes result from the rock fracture where the two sides have been displaced relative to each other on the fault plane, it can be expression that the earthquakes occur near to each fault its activity of that fault. Therefore, the number of earthquakes occurring over time is near the fault, indicating that the fault is more active. As a result, the fault range has a greater seismic risk. To define the seismic hazard zone for each region, is used a term as a seismic source (KELLER & PINTER, 2002). The purpose of collecting regional data is to obtain the necessary knowledge about the geodynamic condition of the area and also to identify the geologic components effective in seismic hazard of the site. The geological structure referred to are actually seismic sources, which are mainly known as active faults and have the potential to cause seismic changes in the earth's crust.

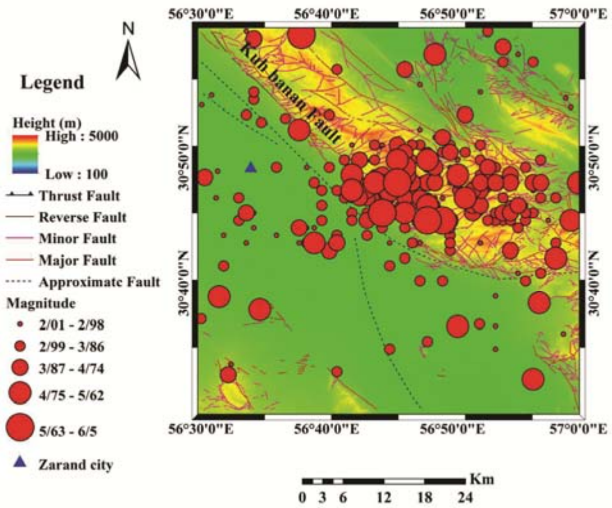

Fig. 4 - Seismotectonics map of the study area

According to the regional seismotectonics map (Fig. 4) and the distribution of earthquakes, most of the earthquakes recorded in the center and east of the study area, and the number of earthquakes occurring are reduced to the north and south. The frequency of earthquakes occurring with magnitude 6 is limited, in particular in the range from 30.40 to 30.50 degrees latitude and 56.40 to 57 degrees longitude, with a large number of earthquakes of medium to low magnitude. As a result, earthquakes with a medium to high magnitude and energy release are not expected to occur in the region.

ESTIMATION OF SEISMIC PARAMETERS

The first step in the estimation of probabilistic seismic hazard in a region commonly consists of the definition and characterization of the relevant seismic sources. The Gothenburg-Richter Initial Distribution Function was introduced in 1956. The Gutenberg–Richter recurrence relationship is an essential and practical relationship in estimating the earthquake hazard. In equation (4), the frequency of earthquakes (Nc) is linearly attributed to relation (1) to magnitude (M) (GUTENBERG & RICHTER, 1956).

$$Log\ Nc = abMN \quad (4)$$

In this regard, Nc is the cumulative frequency of earthquakes, a constant coefficient that changes with the change in the length of the statistical period, b the seismic factor, which increases the size b over a given period, indicates an increase in the magnitude of the earthquake that can occur and the magnitude MN Earthquakes (GUTENBERG & RICHTER, 1956). After controlling the data, the cumulative abundance and frequency of each group was determined and plotted against the magnitude of the earthquake in magnitude (M) and Log Nc (Nc cumulative frequency of earthquakes), and then the best possible line between fitted points and the line formula has been obtained with a correlation coefficient of 91.66% (Fig. 5).

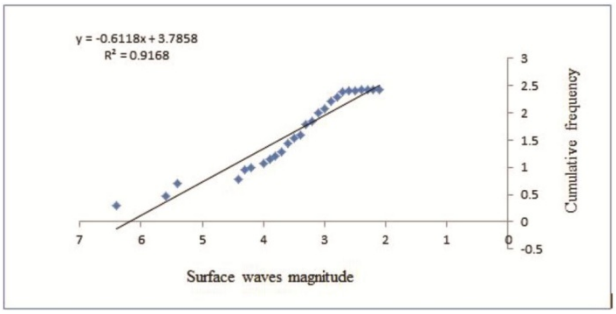

Fig. 5 - The frequency diagram of the surface waves magnitude

Finally, in the statistical method, the least squares of the coefficients a and b are respectively 3.78 and 0.61, so the Gothenburg-Richter formula is obtained as a relation of 5:

$$Log\ Nc = 3.78 - 0.61M \quad (5)$$

Using the data and information available on the twentieth century earthquakes, one can obtain the probability of a seismic event of a certain magnitude for a different recurrence interval. For this purpose, using the Gutenberg-Richter linear relationship, the probability of occurrence of earthquakes over the useful life of the structure is obtained (6, 7).

$$N = 10^{(a-bM)} \quad (6)$$

$$P = 1 - [EXP(-T \times N)] \quad (7)$$

In the above relations, P is the probability of earthquake occurrence, M is the magnitude of the earthquake and T is the useful lifetime of the structure per year.

Using equation 7, the probability of occurrence of earthquakes with magnitudes of 6.5, 7, 7.5 and 8 was calculated for periods of 10 to 50 years (Table 1).

8	7.5	7	6.5	MS/year
54.09	79.29	95.86	99.84	10
78.93	95.71	99.82	99.99	20
90.32	99.11	99.99	99.99	30
95.54	99.81	99.99	100	40
97.96	99.96	99.99	100	50

Tab. 1 - The probability of the earthquake occurrence with the difference magnitude in the study area (by percent)

Seismic hazard analysis of the studied area by a probabilistic statistical method indicates that the probability of occurrence of earthquakes with a magnitude of 6.5 over the next 40 years is within the range of 100% (Table 1).

Effective Factors in Seismic Hazard Zonation

The first step in zoning the earthquake hazard is to create a database and collect the required data. These factors are the magnitude of the earthquake, the distance from the fault (Fig. 6), the depth of the earthquake, the distance from the earthquake surface center (Fig. 7) and the lithology (Fig. 8).

Below is an examination of each of these factors in the region and its role in earthquake risk. The distance from the fault is of special importance because of the close proximity between the fault and the earthquake, and most of the earthquakes are concentrated on the faults. As the fault are further away the earthquake effect is also reduced. The magnitude of the earthquake is also very important because the impact of the earthquake in the region depends heavily on its magnitude. The distance from the earthquake surface center and the depth of the earthquake are also important, as the distance from the epicenter decreases the impact of earthquakes. In addition whatever the earthquake occurrence at a shallower depth, it has more intensity and higher destructive power compared to depths levels, but increasing the depth of the seismic forces in their epicenters increases their destructive power.

Lithology

Damage patterns may vary greatly within small areas, and major damages may occur at sites far from the earthquake source. Sometimes this may be due to different types of building construction however in many cases, the geological characteristics of the site have a large influence on the intensity of the ground shaking. This is the reason that we often see a heavily damaged building at one place while a building of similar construction a block or two away may be completely unaffected (GAO *et alii*, 1996; KELLER & PINTER, 2002).

The effects of sedimentary basins on seismic waves are more extensive than amplifications and resonances caused by soft alluvium near the surface. Complicated interactions between the structure of the basin and the traveling seismic

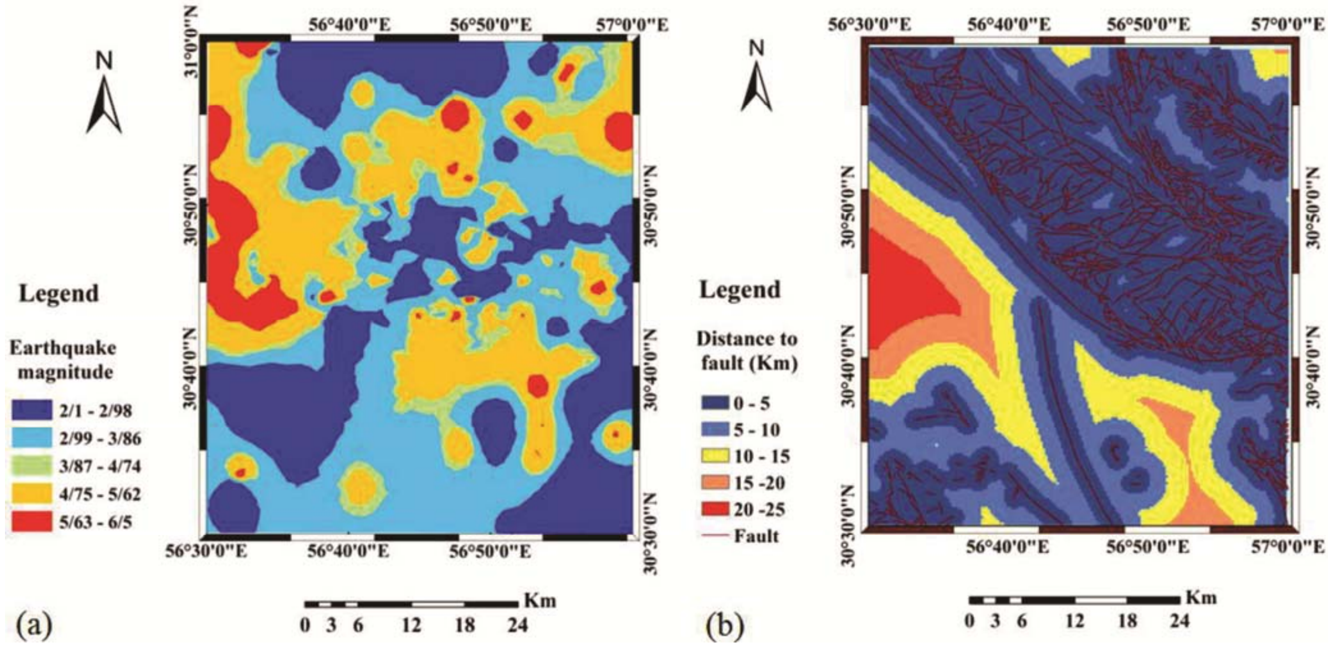

Fig. 6 – Classification maps of a. the earthquake magnitude, b. the fault distance

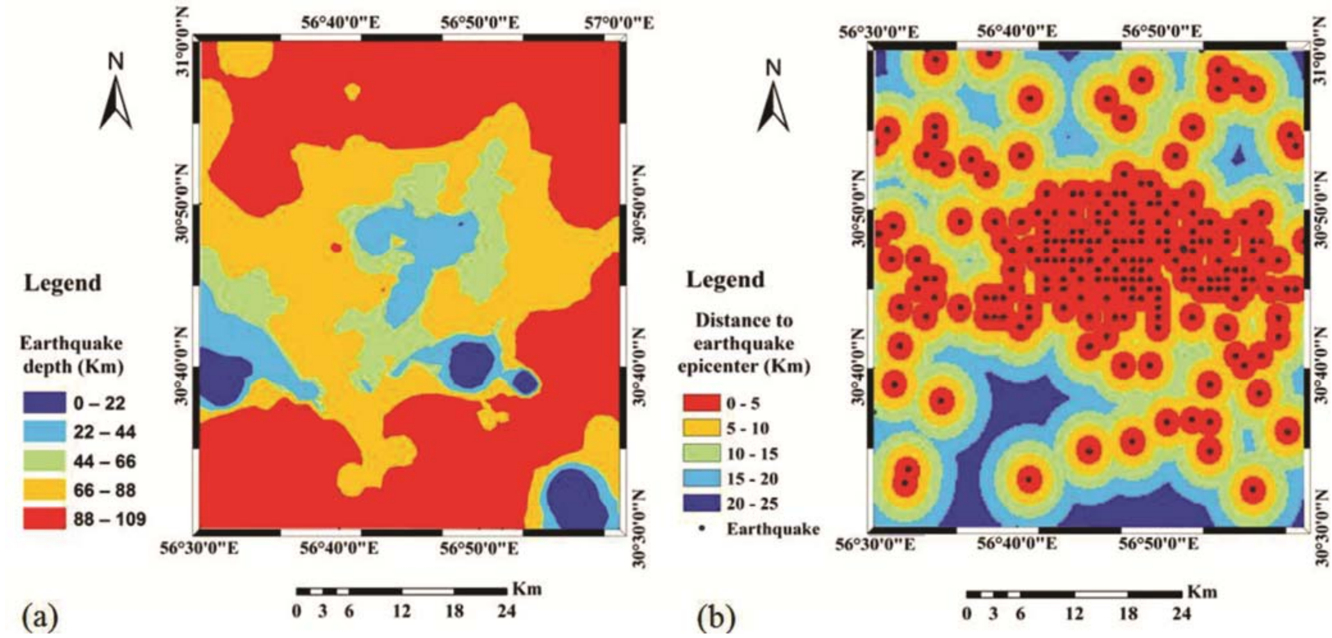

Fig. 7 - Classification maps of a. the earthquake depht, b. the distance of the eathquake surface center

waves can increase the amplitude and duration of shaking during an earthquake. These interactions can focus the waves from the bottom of the basin, thereby concentrating the intensity of strong shaking in small regions at the surface, while diminishing intensity at other sites. Additionally, the edges of basins can effectively trap incoming seismic waves thereby increasing the duration of shaking in the basin (Stein & Wysession, 2003; Gao *et alii*,, 1996). The Zagun, Sorkh shale and Sardar formations during earthquakes are acting as a reducing factor in the velocity and earthquake energy, and the frequency of earthquake waves increases in these rocks, which can lead to destruction Structures. Lalun, Espahk, Jamal and

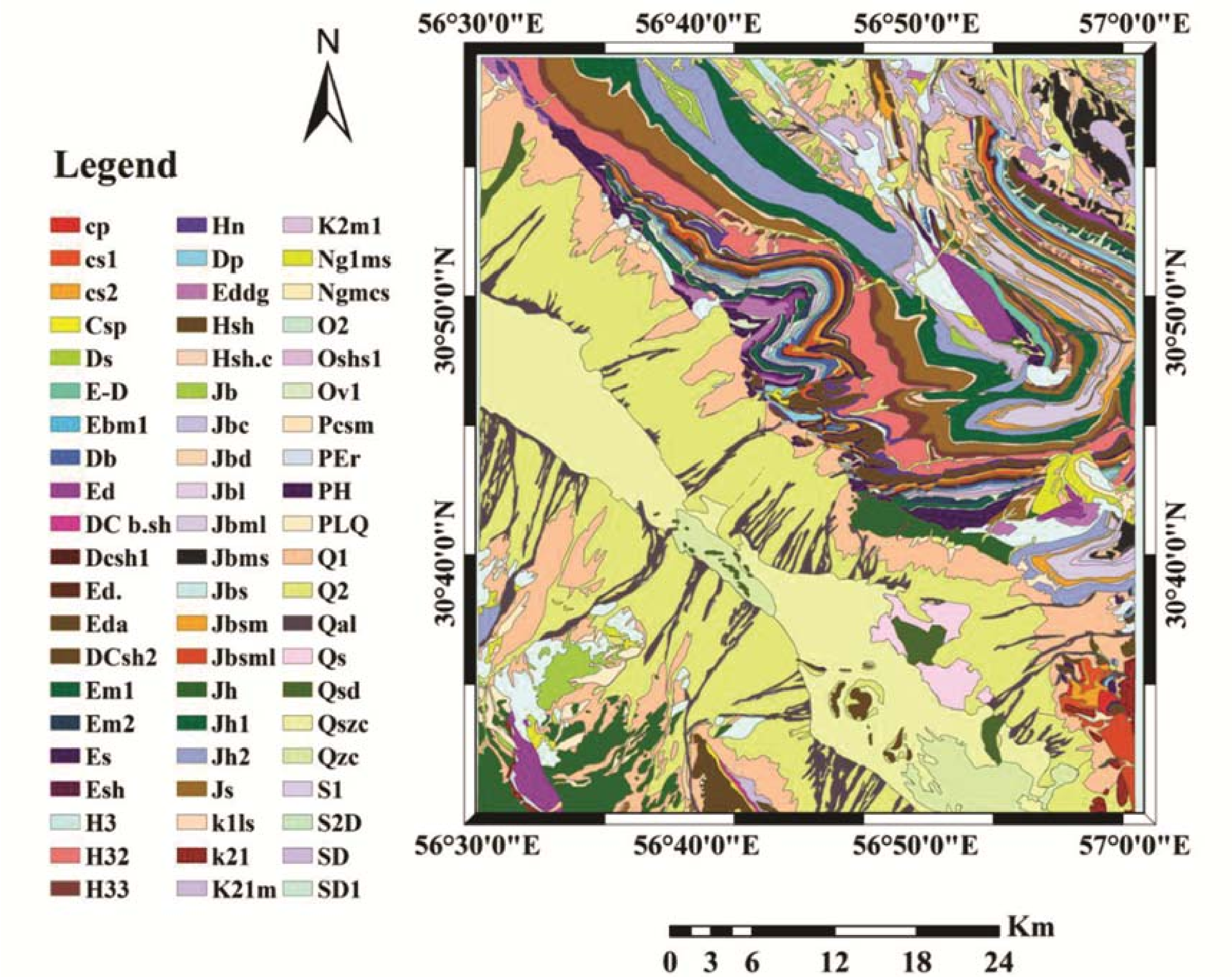

Fig. 8 – Classification map of the rock sequences

Bahram formations because of the hard lithology are showing brittle behaviour during earthquake occurrences and can collapse.

ANALYTIC HIERARCHY PROCESS

The Analytic Hierarchy Process (AHP), introduced by Thomas Saaty (1980), is an effective tool for dealing with complex decision making, and may aid the decision maker to set priorities and make the best decision. This qualitative method creates a hierarchy for the decision parameters and then compares possible pairs in a matrix so that a weight and consistency ratio can be assigned to each element (Saaty, 1988; Saaty, 2008; Estoque, 2012). This technique has been used successfully to map seismic hazard zonation in different parts of the world (Malczewski, 1999; Mohanty & Walling, 2008; Pal *et alii*, 2008; Bathrellos *et alii*, 2009; Erden & Karaman, 2012; He *et alii*, 2014; Karimzadeh *et alii*, 2014; Panahi *et alii*, 2014; Quadrio *et alii*, 2015).

AHP involves structuring a problem into primary and secondary objectives. Upon establishment of the hierarchy, a pairwise comparison matrix for each factor in each level is constructed. Each factor is weighed against other factors within the same level, and correlate with the levels above and below its position. The entire scheme is mathematically joined, resulting in a priority statement for each individual or group.

Build Hierachy

The hierarchical structure of the subject under consideration is presented in figure 9. In this figure, a 3-level hierarchy including objective, criterion, and option is presented. The conversion of the subject into a hierarchical structure is considered to be the most important part of hierarchical analysis. In this section, by analyzing complex issues, the hierarchical analysis process is performed by dividing it into partial elements that are hierarchically linked together. The main objective of the problem is to identify the lowest level of hierarchy and it simplifies the problem.

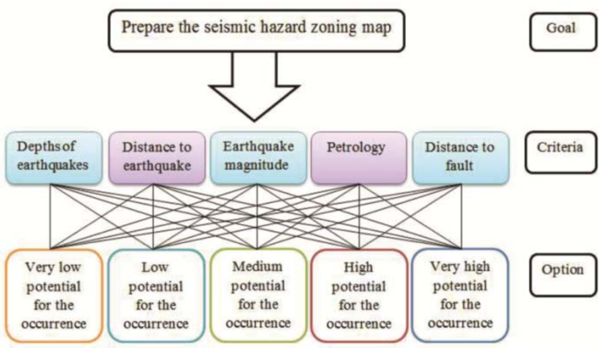

Fig. 9 – The hierarchy structure in order to seismic risk zoning in study area

Determine The Importance Factor Of The Criteria

After the analysis of the problem, the hierarchy of elements of different levels is compared bilaterally, and then, according to the importance of the two criteria, they are valued.

The word "sift", which is presented by hour, is based on the assessment of the importance of two criteria (Table 2).

Numerical value	The importance of parameters relative to each other
1	Equal importance
3	More relatively importance
5	More importance
7	Much more importance
9	So much importance
2,4,6,8	The importance of intervals

Tab. 2 – The verbal statements judgement scale for paired comparison (SAATI, 1980)

Provide Pairwise Comparisons Matrices

In this step, using a paired comparison method, a matrix of 5 × 5 dimensions was created and different criteria were compared in two and the corresponding values were determined based on pairwise comparisons which was proposed by SAATY (1980) (Table 3). To calculate the weight of each criterion, the geometric mean of each row of the matrix was divided by the total geometric mean of the columns.As shown in Table 3, distances from the fault and the magnitude of the earthquake are considered to be the most important measures in the earthquake risk in the region, having weights of 0.503 and 0.26, respectively. Similarly, in tables 4 to 8, the weight percentages of the five factors affecting the earthquake risk are presented.

Weight	Earthquake depth	Petrology	Distance to earthquake epicenter	Earthquake magnitude	Distance to fault	Criteria
0.503	9	7	5	3	1	Distance to fault
0.26	7	5	3	1	0.333	Earthquake magnitude
0.136	5	3	1	0.333	0.2	Distance to earthquake epicenter
0.068	3	1	0.333	0.2	0.143	Petrology
0.034	1	0.333	0.2	0.143	0.111	Earthquake depth

Tab. 3 - The standardized weights of each effective parameter in seismic risk based on AHP

20 - 25	15 - 20	10 - 15	5 - 10	0.5	Distance to fault
0.034	0.068	0.136	0.26	0.503	Weight

Tab. 4 - The standardized weights according to distance of fault based on AHP

5.62 – 6.5	4.75 – 5.62	3.87 – 4.74	2.99 – 3.86	2.1 – 2.98	Earthquake magnitude
0.503	0.26	0.136	0.068	0.034	Weight

Tab. 5 - The standardized weights according to earthquake magnitude based on AHP

20 – 25	15 – 20	10 – 15	5 – 10	0 – 5	Distance to earthquake epicenter
0.034	0.068	0.136	0.26	0.503	Weight

Tab. 6 - The standardized weights according to distance of earthquake epicenter based on AHP

Weight	Formation name	Unit
0.001	Undivided deposits.	Ud
0.003	Quaternary deposits.	Q1,Q2,Qs,Qsd,Qal,Qzc,Qszc,PlQ
0.005	Dark red sandstone, silty shale, siltstone (Zagun Formation)	Esh
0.009	Shale, sandstone, siltstone, carbonaceous shale, coal intercalations (Shemshak Formation)	Js
0.012	Shale, sandstone, siltstone, carbonaceous shale, coal intercalations (Shemshak Formation)	Cs1, Cs2
0.017	Shale, limestone, sandstone, quartzite (Shishtu Formation)	DC1sh, DC2sh
0.018	Siltstone, shale, sandstone, carbonaceous shale, coal intercalations, conglomerate sandstone, limestone (Hojedk Formation)	Jh1, Jh2
0.02	Silty shale, siltstone, sandstone intercalations, limestone (Naiband Formation)	H33, H32, Hn
0.022	Conglomerate, sandstone (Kerman conglomerate)	Pcsm, Pckc
0.022	Dolomite (Soltanieh Formation)	Ed
0.024	Calcareous sandstone, sandy limestone, silty shale, quartzite, dolomite, gypsum (Padeha Formation)	Dp
0.027	Sand stone, quartzite, shale, sandy limestone (Sorkh shale Formation)	PH
0.029	Dolomite (Shotori Formation)	Hsh
0.031	Shale, sandstone, dolomite, limestone, gypsum, quartzite (Sibzar Formation)	Ds
0.032	Conglomerate, sandstone, marl, gypsum, silty marl.	Ng1ms ،Ng2csNg2sc ،Ngmcs
0.033	Red-purple sandstone, tuffaceous sandstone, intermediate-basic volcanic rocks (Rizu Formation)	PER
0.034	Amonite bearing limestone, siltstone, silty shale, sandstone (Badamu Formation)	Jbd
0.035	Sandy limestone, silty shale, sandstone, siltstone (Niur Formation).	S1D, S2D, S1
0.037	Silty shale, sandstone, limestone, marl (Shirgesht Formation).	Osh1, O2, Ov1
0.043	Sandstone, silty marl, dolomite and limestone intercalation (Kuhbanan/ Mila Formation).	Em1, Em2
0.046	Sandstone, silty marl, limestone intercalations (Bidu Formation).	Jb, Jbc, Jbs, Jbl, Jbml, Jbsm, Jbms, Jbsml
0.055	Orbitolina limestone, siltstone, silty marl, gypsum	K1ls, k21, k21m, k2m1
0.067	Alternations of dolomite, Sandstone, shale limestone, gypsum, basic to intermediate volcanic rocks (Desu Formation).	EddgEd
0.081	Brachiopoda bearing limestone, dolomite, siltt shale, sandstone, quartzite in lower part (Bahram Formation).	Db
0.085	Limeston, dolomite limestone, dolomite (Jamal Formation).	CP
0.092	White-light limestone (Espahk Formation).	Hsh
0.120	Red arkosic micaceous sandstones (Lalun Formation).	Es

Tab. 7 - The standardized weights according to lithology unit based on AHP

88 -109	66 - 88	44 - 66	22 - 44	0 - 22	Earthquake depth
0.034	0.068	0.136	0.26	0.503	Weight

Tab. 8 - .The standardized weights according to earthquake depth based on AHP

...	7	6	5	4	3	2	1	N
...	1.32	1.24	1.12	0.9	0.58	0	0	IIR

Tab. 9 - Random Matrix IIR Values

Very high	High	Medium	Little	Very little	Seismic risk
24.92 %	35.46%	16.61 %	11.86%	8.72 %	Area percent

Tab. 10 - Percentage of the area with the seismic risk in the study are

Comparison's Compatibility Survey

To calculate the inconsistency rate, we use the agreement ratio, which computes the agreement index (*CI*) by several steps:

1. Determine the weighted sum vector by multiplying the first criterion in the first column of the original dual comparison matrix, then multiplying the second criterion in the second column and, thus, until the last criterion, and finally summing the values in the rows.
2. Determine the agreement vector by dividing the weighted sum vector on the standard weighted previously set.
3. Calculate (λ) and agreement index: (λ) is the mean of agreement vector values. (λ) obtained is 5.25. In this formula n is the number of criteria under consideration.
4. Accumulation Index (*CI*) is calculated using the following equation:

$$CI = \frac{\lambda - n}{n-1} \tag{8}$$

$$CI = \frac{CI}{IIR} \tag{9}$$

In this study, the λ value was 5.5 and the agreement value index was equal to 0.0625. Also, calculating the incompatibility rate is 0.055, which is less than 0.1. Therefore, there is acceptable compatibility in pairwise comparison (Table 9).

PREPARATION OF EARTHQUAKE HAZARD ZONATION MAP

One of the important solutions to reduce the damage caused by earthquakes is to assess and quantify areas susceptible to earthquakes through the provision of earthquake hazard zonation maps. There are several methods to prepare zoning map, among which the AHP method was used for the study area.In this method, required maps such as distance from the fault, the magnitude of the earthquake, the distance from the epicenter, lithology and the depth of the earthquake in the GIS environment using the Arc map software were prepared and after scoring the factors required in the AHP method, the zoning map was presented.

These maps are based on the risk of each region different colors will be distinguished from each other. Zoning maps in alert and rescue networks can be effective.

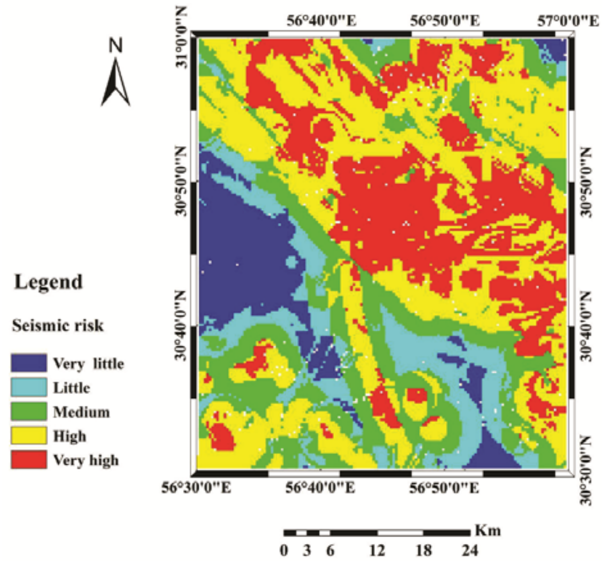

Fig. 10 - The seismic risk zoning map of the study area

These maps, which differ from each other according to the risk of each region, will allow authorities to plan and manage relief and alert operations in a short time. According to the hazard zonation map (Fig. 10) and the percentage of earthquake hazard areas (Table 10), it appears that the studied area is seismically hazardous.

The highest percentage of earthquake hazard in the study area is in the area with a high risk of 35.43%, and the area with a very high risk area has an area of 24.29%.

CONCLUSION

The seismic hazard analysis of the study area with probabilistic and analytic methods indicates that Zarand is one of the most active seismotectonic units in Iran and many faults are located near this city. In the probabilistic method, the Gothenburg-Richter method was used to indicate that earthquakes with a magnitude of 6.5 in the next 20 years and a magnitude of 7 in the next 30 years with a possible 99.99 percent probability. In addition the earthquake zoning map in ArcGIS10.2 software was prepared based on magnitude, depth, distance from the fault and distance from the epicenter. In general, in the geologic map of the Zarand, scale 1:100,000, has been shown the more probable area for earthquakes located in the central and north-northeast regions.

The west side of the map is an area with probability of a higher-magnitude quake, a low depth and a distance from the fault of about 20 to 25 kilometers, and the Zarand city is located near this area. The study also examined the risk of earthquakes in the studied area using AHP models. The findings of the AHP hierarchical zoning map show that 24.22% of the studied area is at very high risk. High-risk areas are mainly related to the eastern, central and northern parts of the area, and the Zarand city is located in a medium to high risk area.

The method in this study provides an effective and practical estimation of earthquake risk to different seismic hazard zones in other areas.

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