J. Basic. Appl. Sci. Res., 3(5)458-465, 2013
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ISSN 2090-4304
Journal of Basic and Applied Scientific Research
www.textroad.com

The Assessment of Urban Physical Development on the Periphery of Seismic Faults and Vulnerable Natural Zones (Case Study: the City of Amol in Mazandaran Province, Iran)

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ABSTRACT

The outbreak of several earthquakes in different places of Iran in recent years and their negative consequences on urban areas confirm this fact that choice of living place has always been affected by the natural properties of environment and its geologic structure. Regarding its placement across the different faults of northern Alborz, the city of Amol in Mazandaran province is one of these places. The aim of this article is to study the probability of the outbreak of earthquake and also to analyze the role of the physical and horizontal development of the city in this event. To this end, the isoseismic curves and the maps measuring seismic hazard breadth have been drawn, using topographical and geological maps with a scale of 1: 250000 and also applying Arc GIS and instrumental and historic seismographic data. The results of the study shows that there is a great probability of the happening of earthquakes with large scales in Amol, and in eastern and western parts, the city has speedily expanded towards the high altitudes within the range of second grade faults. finally, Considering the dominant characteristics of coastal and mountainous regions and also the friction of natural slopes, fundamental researches in mountainous cities in order to know the natural mechanisms, the intensity and the kind of geomorphologic processes, and to measure the probability of danger in different parts are of primary importance.
KEY WORDS: Fault, earthquake, the seismic vulnerability of cities, city of Amol.

INTRODUCTION

Earthquake is considered to be the most sorrowful and the most horrific of natural disasters that afflicts many countries of the world. Iran is located in the middle part of orogenic Alpian belt; the movement has not finished and the final balance has not been achieved yet. Alborz, Zagros, and the central Iran are the three seismic regions of the country [1]. In coastal and mountainous areas that morpho-dynamic factors are active, urban development boundaries have expanded to the coastlines and the mountains. The settlement of urban habitations on natural slopes makes the issue more complicated [2]. In these areas, making human habitations on slopes is very dangerous because the boundaries of faults, the kind of the materials and their solidity and the geomorphologic properties of human habitations are not properly observed. [3]. Considering the dominant characteristics of coastal and mountainous regions and also the friction of natural slopes, fundamental researches in mountainous cities in order to know the natural mechanisms, the intensity and the kind of geomorphologic processes, and to measure the probability of danger in different parts are of primary importance [4]. Many cities in the north of Iran are always susceptible to earthquake because Alborz Mountain is aseismic canon experiencing earthquakes as big as 8 Richter on scale [11]. The city of Amol in Mazandaran with a population of about 200302 in 2003 is one of the cities that according to the Research Center of Construction and Building has young and active faults that make it a great danger zone. Because of the horizontal development of the city towards the faults in recent years, many parts of Amol are now on the fault line [5]. This situation, while increases the possibility of the danger, necessitates the plan to strengthen the buildings and prevent the physical growth of the city towards the faults. The aim of this work is to study the seismic properties of Amol, the extension of the danger zone, and also to analyze the urban development on the fault line.

LOCATION OF STUDY AREA

The city of Amol with 3074.4 square kilometers in extent forms 12.94 percent of Mazandaran province. It is located in the center of province and bounded on the north by Mahmudabad, on the northeast by Babolsar, on the east by Babol, on the south by Tehran and on the west by the city of Noor. Amol lies at latitude 35° 36' to 36° 40'

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and longitude 51° 43' to 52° 33'. The altitude of the city from the sea is 79 meters. Considering earth reliefs and topographical features, Amol is divided into three regions [6]:

1: The plain region: with a slope of 5%, the plain region starts from the coast stripe to the altitude of 100 meters and its top lies in Haraz.

2: The foot of the mountain: it extends from the altitude of 100 meters to 500 meters and has a steep slope.

3: The mountainous region: it starts from the altitude of 500 meters and extends to Kuhsang and Imamzadeh Hashem in south.

Damavand, the highest point of Iran with an altitude of 5671 meters, is located in the south of the city. The Haraz River 150 meters long is one of the major rivers of Amol and Mazandaran (Fig.1).

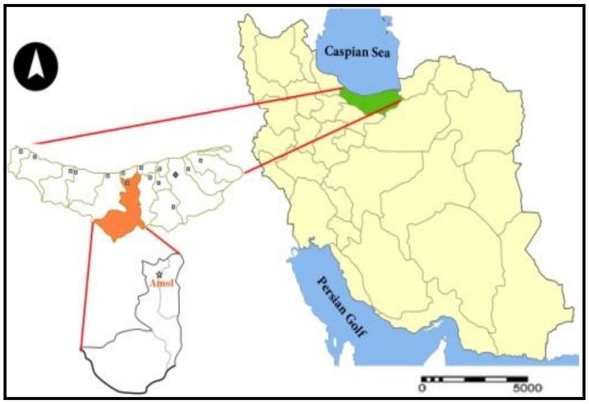

Fig 1: Geographical position of study area

MATERIALS AND METHODS

The methodology of the study is both quantitative and qualitative, and all the given data and sources are based on library documents on this subject. To analyze the faults and urban development, Landset Satellite images (ETM^+, 2008) have been used. In order to study the tectonic tremors, maps of danger zones and isoseismic surfaces are drawn, using historical seismic data (before 1900 AD) and instrumental seismic data (after 1900 AD) that have been gathered from geophysics organization of Tehran University. Topographical (1: 250000) and geologic maps (1:100000, 1: 250000) are applied to observe the case location and provide numerical-height models, and also to investigate the active faults and lithological units. After examining natural features, geology, and lithology of the location, first the local distribution map of seismic focuses of the 20^{th} century in Amol and also the isoseismic surfaces are drawn by using geographic information system and Arc GIS software. After that, the hazard breadth map is categorized in several classes and the situation of the towns and villages is defined (Fig. 2). This cannot be achieved without drawing different buffers with different distances from the main fault and mixing it with the map of the local distribution map of seismic focuses. The density (Eq.1) and the weight (Eq. 2) of each buffer are also calculated:

$$D = 1000 \times N\,pix\,(sxi) / N\,pix\,(xi) \qquad (1)$$

$$W = 1000 \times N\,pix\,(sxi) / N\,pix\,(xi) - 1000 \times \sum N\,pix\,(sxi) / \sum N\,pix\,(xi) \qquad (2)$$

Where,

D: the density of the earthquake centers

N pix (sxi): the number of seismic focuses in each buffer

N pix (xi): the number of pixels of each buffer

∑N pix (sxi): total number of seismic focuses

∑N pix (xi): total area of the buffers

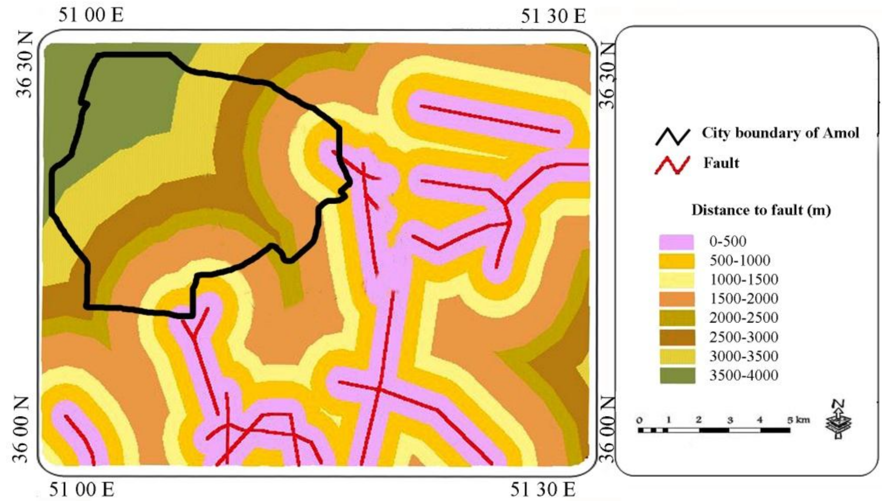

Fig 2: The map of extracted buffers from the present faults in Amol and the around regions

RESULTS AND DISCUSSION

In current categories, the city of Amol considers to be one of the coastal and mountainous regions of the country. Today's location of residence and establishment of new centers, the economic factors are considered. And against the land of cheap natural forces are ignored. It said that more than 90% damage to buildings and architectural alternatives is not relevant. But incorrect positioning or lack of environmental planning and performing financial and human make-up will cause severe damage [7].

Most engineers are completely unaware of the consequences of natural hazards such as earthquakes and more attention to building strength in knowing if the land on which the city is built. Zoning earthquake-prone areas of useful measures to reduce the severity of the damages is considered, it is hereby be limited use of high-risk areas. Construction of some buildings in these zones can prevent by identifying risk zones in cities in low-risk areas of vital arteries decided [6]. Lineaments as seismic sources, including plate movements and withdrawal are major factors, thus, away from the faults could be considered as one of the main parameters of seismicity. Location of faults in Amol county and weighting based on distance from the fault; the county is considered a moderate seismicity (Fig. 3).

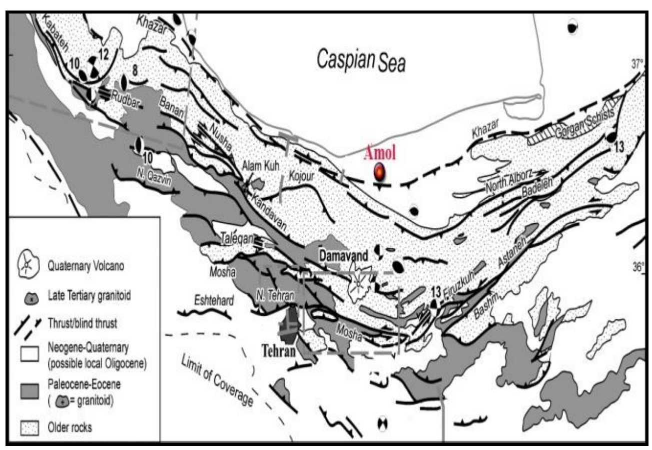

Fig 3: Geology of the Alborz and, inset, its location within the Arabia–Eurasia collision. Geology derived from the National Iranian Oil Company (1977, 1978) [8, 9], and location of Amol in northern Alborz.

Geologic and lithologic conditions:

Overall structural relief from the Alborz Mountains to the southernmost Caspian basement is ~25 km. It is a part of the Alpine-Himalayan organic belt in Western Asia, which is bounded by Caspian Sea on the north and Central Iran on the south [10]. The study area is a small part of the central Alborz Mountain consisting of dolomite, limestone, shale and sandstone. It is marked by a number of thrusts that are oriented in east-west and northeast-southwest direction. The major structures such as thrust and faults that have been considered as important parameters for the earthquake studies have been discussed. The area of investigation is traversed by number of thrust of regional extent, which generally shows NW-SE with northeasterly dips varying 30-59 degree. The various litho-units of area have been displaced by a number of faults. Most of these faults are transverse with reference of the thrusts. It is observed that geology, geomorphology and geo-structure condition in area causing the vulnerable zone for earthquake and landslide hazard risk [11]. Further any change in this condition had brought about adverse environmental implications.

The Alborz Mountains range from the southern end of the Talesh to its junction with the Kopeh Dagat. The overall trend of the mountains changes from N110°E in the western Alborz to N80°E in the eastern Alborz, and a marked hinge occurs near longitude 52.5°E. According to Jackson et al. [10], most of the focal mechanisms in this mountain belt show either reverse faulting or left-lateral strike-slip on faults parallel to the regional strike of the belt [12]. Almost all significant earthquakes in the region were analyzed considering the events occurred in a long period of time, form 1990 to 2009. These earthquakes were recorded at different stations; located in the Alborz region, Northern Iran and covered a wide range of hypo central distances (Fig. 4).

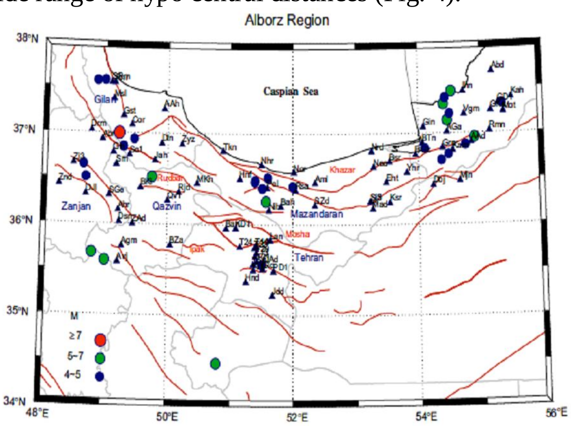

Fig 4: Epicenter location of the earthquakes analyzed for the present study (circles), strong-motion stations (triangles) and active faults in each part (red solid-line). Light gray lines show the province boundaries [12]

Based on seismic data, the abundance of earthquake happenings in Amol is measuring 3.5 on the Richter scale. Following seismic properties of the north of Iran, the depth of seismic focus is low (30 to 40 kilometers). Many of the earthquakes have happened on the periphery of the around faults, and the faults maps show that urban growth in western, southern, and southeast parts is across the secondary and minor faults. Earthquakes measuring more than 3.5 on the Richter scale show good conformity with minor and major faults (Fig. 5).

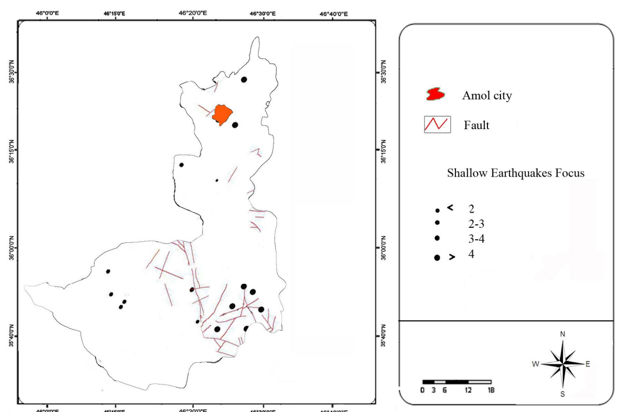

Fig 5: Instrumental seismic map of surface focus of Amol in 20th century

Each of the mentioned classes in this picture is defined in relation to hazard assessment in the case area, considering such parameters as local distribution of seismic focus in 20th century, different distances around the main fault and its combination with the local distribution map of seismic focus, density, and weighting the periphery of faults. In these classes, by low seismic danger it means (earthquakes measuring 1 to 2 on Richter scale), fairly low (earthquakes measuring 2 to 3 on Richter scale), average (earthquakes measuring 3 to 4 on Richter scale), high (earthquakes measuring 4 to 6 Richter on scale) and very high (earthquakes measuring more than 6 Richter in scale). Based on the potentials of the environment and its susceptibility to hazards, the breadth of the danger zone differs in each area (Fig. 6).

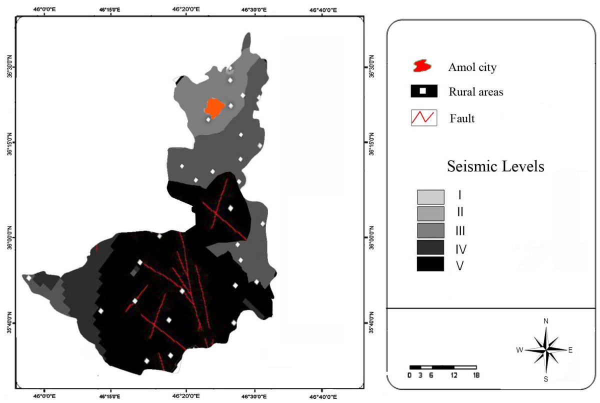

Fig 6: Adaptation map of isoseismic curves and major faults in Amol

As depicted above, a great part of the faults are located in south and southwest of Amol and the horizontal urban growth towards the faults has increased the probability of danger. Based on the maps and seismic history, the city of Amol lies on isoseismic plate of 3 or more on Richter scale. Based on the seismic hazard map, Amol is located in the area with breadth of average or high danger (Fig. 7).

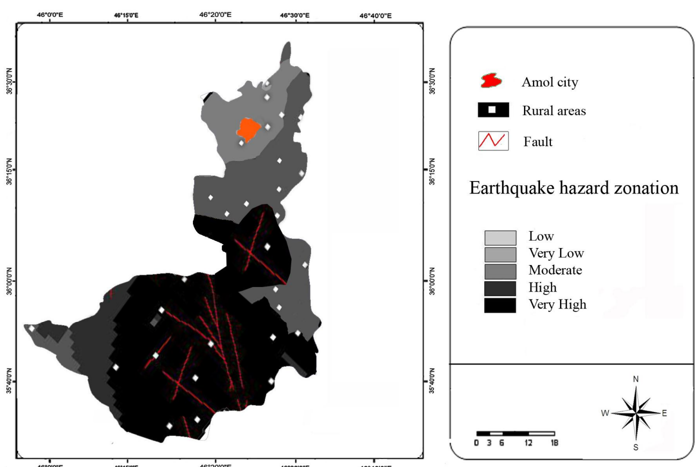

Fig 7: Earthquake hazard zonation in Amol

Process of physical growth of Amol:

During different periods, Amol has grown and developed in various aspects. The process of physical development of Amol can be studied by the available information and map of each period (Fig. 8):

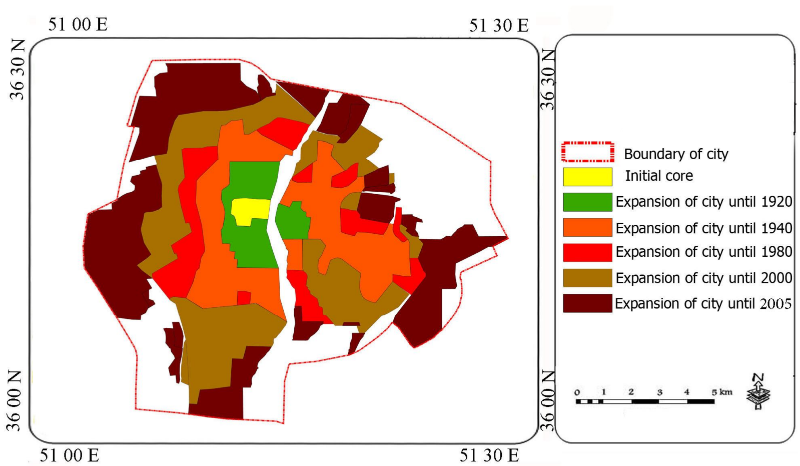

Fig 8: Map of physical development Process of Amol from 1920 to 2005

The process of physical and population growth rate of Amol shows that spatial structure of the city has changed during different stages. Table 1 shows the division of the developmental periods of the city.

Table 1: Urban growth of Amol and its consequences in contemporary era (1920-2005) [13]

Developmental Years	The Area of City (hectare)	Important Events
1920-1940	63	Dehydrating the moats around the city, building perpendicular lines of streets, the formation of checkered plates, maintaining the market structure, the establishment of administrative-government departments like municipality (1924), Pahlavi high school (1931), finance office (1929).
1940-1960	324	Widening the Haraz road, better access to Tehran and the improvement of business relations, extending the urban equipments and establishments like electricity network, water reticulation, telephone, the formation of new urban sections like cinema and stadium, the foundation of stock market, and landed property and estate transactions.
1960-1980	800	Urban growth in west and north east and the destruction of gardens and agricultural lands at the beginning of this period, ecological division and class habitations according to social and economic changes, urban growth in east and southern parts of the city at the end of the period.
1980-2000	1300	Many fold increase in area and population comparing with the previous periods, unprincipled and illegal building construction especially across the roads to other cities regarding the particular situation at the beginning of the Revolution, the formation of nonconforming textures because of the transformation of the around villages to urban texture like Pelk Olia and Sofla (southwest), Rahmatabad (northeast), Klakser (north), Ghorogh (northeast), Bazyarkola (south).
2000-2005	2000 1900 2005 2824	The formation of informal habitation (Dabaghchal in northwest), the approval of the first comprehensive (1983) and detailed (1985) plan, relative control of building construction, the approval of the second comprehensive (2000) and detailed (2005) plan, supervising the constructions in peripheral zones, the necessity of observing the principles and laws of urbanism, prevention of irregular urban growth.

The study of urban physical development in the years of 1965 to 2005 shows that the development has not been in harmony with the population growth. The physical growth has exceeded the population growth; therefore a low density texture is created. As depicted in table 2, the gross population density that in 1975 was equal to 142 persons in Hectare decreased to 71 persons in 2005. On the other hand, its gross capitation increased from 71 to 141 square meter; while in both first and second comprehensive plans, the optimum use of valuable fields inside the city is planned to prevent the irregular urban growth and also to prevent the destruction of agricultural lands an optimum population density of 145 persons is considered for the city. If the physical growth of the city was according to the gross capitation in1975 i.e. 71 square meter, the area of Amol would be 1418 Hectare by now, while the current area of the city is 2824 Hectare more than what expected in 1975. This unexpected population density is the result of a transmittal pattern that has caused instability in urban structure.

Table 2: Comparing population growth with the area of the Amol from 1965 to 2005 [13]

Year	Population	Area (Hectare)	Gross Density	Gross Capitation	Optimum Area based on the first comprehensive plan (1975)	Difference of current situation with optimum (Hectare)
1965	40061	331	121	83	282	49
1975	68963	487	142	71	487	-
1985	118242	856	138	72	840	16
1995	159092	1900	84	119	1130	770
2005	199734	2824	71	141	1418	1406

The population of the city has increased from 222252 in 1955 to 199734 in 2005, and during these years the area of the city from 377 hectares has reached to 2824 hectares [12, 13, 14]. It means that the population has grown nine times and the area 7.5 times in these years. In fact during the last 50 years, 49 hectares is added to the area of the city and 3550 persons to its population each year. Although the population growth has exceeded the amount of the area, the acceleration of the area rate has been more than the population rate. During 1965 to 2005, the growth rate of the area of the city has been 5.51 % and the growth rate of the population has been 4.1 % (Table 3).

Table 3: Growth-Rate Changes of Amol during 1965-2005

Year	1965-75	75-85	85-95	95-2005	1965-2005
Population Growth Rate	5.58	5.54	3.1	2.3	4.10
Gross Density Rate	1.61	-./29	-4.8	-1.7	-1.32
Area Growth Rate	3.9	5.8	8.3	4	5.51
Capitation Growth Rate	-1.55	./14	5.15	1.7	1.33

Source: House and Population Census from 1965 to 2005

In recent decades, the city of Amol has experienced rapid and accelerative growth both in population and the area. Generally, in spite of the decrease in population growth in the past two decades and the presence of major obstacles in horizontal development of the city towards the low danger zones, the relative density of the population is increased and the city is extended towards the seismic, and also other natural disasters, hazard regions.

CONCLUSION

The settlement of the many cities of Iran on the slopes and the placement of quaternary faults in the boundary between mountain and plain are the major obstacles to urban development. Amol is one of the cities that part of it lies on the fault. With growing urbanization during the last years and the presence of obstacles in low danger regions of the north, the city of Amol is speedily extending towards the southern high danger regions and mountainous altitudes. Therefore, human habitations are placed on the fault line, and the relative density and tension have increased during these years. These factors along with extensive change of natural use of land to residential and un-residential use have left different consequences that increase the probability of the happening of such events as earthquake, landslip, and earth thrusting. In other words, this situation threatens the new-built constructions with seismic hazards. In southern and eastern parts, regarding the distance from the fault lines and their periphery, urbanization has extended towards the minor and second-grade faults. The city is also developed across the foundations with average resistance to urban loading. On the whole, parts of the city have extended on the periphery of communication networks and surface water systems that are themselves settled on the faults. The continuance of such urban extension towards the vulnerable natural areas causes numerous problems in future. Therefore, it is essential that any kind of plan in relation to urban horizontal development is devised with complete study and assessment of tectonic and natural features of the regions, and urban development across the faults and the seismic hazard regions should be prevented.

Acknowledgment

We are thankful to the Department of Urban and Regional Planning in Universiti Teknologi Malaysia (UTM) and International Doctorial Fellowship (IDF) for providing facilities for this investigation.

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