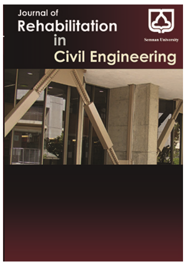
Journal of Rehabilitation in Civil Engineering 1-1 (2013) 1-14



journal homepage: http://civiljournal.semnan.ac.ir/

Earthquake Vulnerability and Seismic Risk Assessment of Bandar Abbas in South of Iran

A.A. Fatemi[1], Z. Tabrizian[2], G. Ghodrati Amiri[3*] and S.A. Razavian Amrei[4]

1. Ph.D., Faculty Staff, Islamic Azad University, Pardis Branch, Postal Code: 135-16555, Pardis new city, Tehran, Iran.
2. Ph.D. Candidate, College of Civil Engineering, Babol Noshirvani University of Technology, Postal Code: 47148-71167, Babol, Iran.
3. Professor, Center of Excellence for Fundamental Studies in Structural Engineering, School of Civil Engineering, Iran University of Science & Technology, Postal Code: 16846-13114, Tehran, Iran.
4. Assistant Professor, Department of Civil Engineering, Payame Noor University, Tehran, Iran.

Corresponding author: *ghodrati@iust.ac.ir*

ARTICLE INFO

Article history:
Received: 12 October 2012
Accepted: 13 January 2013

Keywords:
Seismic risk assessment
Seismic vulnerability
Bandar Abbas
Iran

ABSTRACT

Bandar Abbas (center of Hormozgan province) is the most important port city in the south of Iran because of its historical places, cultural, economic, social and political importance. High risk of earthquake occurrence in this city and its province indicates the necessity of surveying the seismic vulnerability of buildings. The object of this paper is collected from existing Buildings, compiled by aggregating data from sidewalk surveys and other observations. Estimated loss distributions and damage were mapped on area by area. Seismic hazard in the area was obtained using the seismic source zones for a probability level of 10 percent occurrence in 50 years. Finally value of vulnerability was mapped on seismic zones in each area. The older areas of the cities are expected to suffer the highest amount of damage and the highest seismic hazard occurs in these areas as well. We can realize the general vulnerability of the city.

1. Introduction

Iran is one of the most seismically active countries in the world, which is situated over the Alpine-Himalayan seismic belt and is one of those countries that has lost many human lives and lots of money due to occurrence of earthquake. Bandar Abbas due to its special features, including highly dense population, political, and economical port, is very important. In this regard the evaluation of seismic vulnerability of building is very necessary.

The existence of the active Makran Fault deposits of Bandar Abbas plane and also the occurrence of severe past earthquakes, all show the high seismicity of this region [1, 2].

There are many methods to achieve vulnerability map in combination with seismic hazard map in order to obtain risk map [1]. The risk that a building experiences damage more severely than that it was firstly designed for, is a function of two principal factors: structure's vulnerability and site seismic hazard [3]. Seismic vulnerability in wide areas is usually assessed based on inventories of structural parameters of the building collection, especially in high hazard countries like Iran. Ambient vibrations analyses seems to be an option to determine the vulnerability of buildings. The modal parameters extracted from these recordings would give the researchers very useful information about the building's class that may be found in the study area. The distribution of the classes in the areas will lead to a vulnerability map [4]. Different techniques are often used to assess the vulnerability of existing buildings that are usually considered the most vulnerable. These methods were developed for area data collection. Many of them are based on the inventory of structural parameters of the design collected by visual inspections and related to observational data of damage in past earthquakes [5, 6 and 7]. Nevertheless, these methods are well modified in regions with high seismicity where recent significant damage due to earthquakes has been observed (like bam earthquake 2005 in Iran). Indeed, they are generally used for the calibration of the vulnerability or risk curves, accounting for the specifications of the structural design in each region.

2. Site introduction and study method

Hormozgan, a mountainous province, is one of the southern provinces of Iran, $25^{\circ}24'$ up to $28^{\circ}57'$ Northern Latitudes and between $53^{\circ}41'$, $59^{\circ}15'$ Eastern Longitudes. Bandar Abbas, center of Hormozgan province is located in coastwise of sea and has hot and humid weather and long hot summers and short mild winters.

To assess vulnerability of this city, Bandar Abbas was divided into three urban zones and was numbered using the existing urban maps Fig. 1. Some information was collected from Bandar Abbas local engineers, local builders and organizations, for instance, kinds and vulnerability of the structures, vacant houses, population distribution and some other data. To gather needed information, special forms were designed in accordance with suggested forms in FEMA154 (ATC21) [8] and other available references. Also local needs such as inclusion of potential of landslide, or narrow streets and their potential to be blocked due to falling of buildings, lifelines such as pipeline, gas line, type of construction and their quality were included in the prepared forms. It is also essential to study vulnerability of lifelines, hospitals, fire stations, populated places (like school, hotels) and their ability to serve people after major earthquake occurrence. However, due to a determined study target, only dominant buildings in each section were studied. Outcome of the related forms will be presented in other sections.

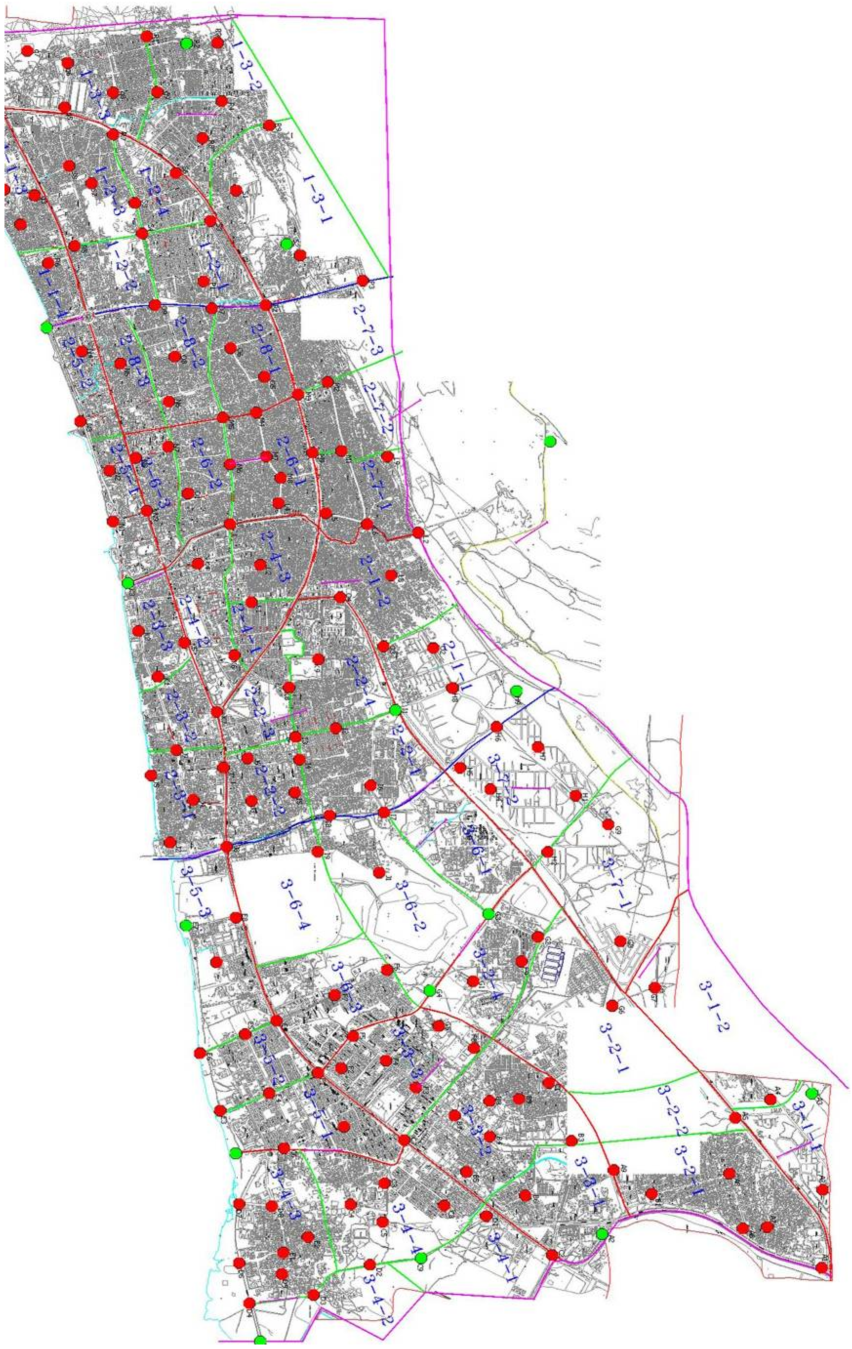


Fig. 1. Primary map of Bandar Abbas zones.

2.1. Studied building and facilities

Bandar Abbas is classified as a high-risk region according to Iranian Code of Practice for Seismic Resistant Design of Buildings (Standard No. 2800) [9]. The buildings studied are all common types of construction in the area, such as reinforced concrete (RC) and steel structures, masonry and adobe buildings. The latter is mostly located in the center and sometimes scattered around city. Old texture of city is located in the center and near the seashore. This kind of scattering texture makes it hard to evaluate the exact vulnerability as a whole. Enormous variations are noticeable in types and quality of construction according to ancient and new areas of Bandar Abbas. Furthermore, different types of soil or different levels of underground water due to gradient of water resources influence the level of vulnerability. To study the vulnerability, the city was divided into some areas. For the easier surviving the areas numbered. Fig. 1 shows these areas and their local centers, the main feature of these divisions is the probability of vulnerability regarding the type and quality of constructions, soil condition such as soil type according to geo-seismograph records, potential of landslide, and underground water level.

2.2. Classification of problems and constructional defect in the area

According to field survey in this study some major problems were classified and identified. This categorization was performed according to foundation, site effect, constructional defects and topographic features. Hereby, some vulnerable conditions, which make the site hazardous, will be described.

Because of proximity of Bandar Abbas to Persian Gulf, the underground water level is high which would cause problems in soil bearing capacity. The soil strength in some areas reaches values as much as 0.7 kg/cm^2. Another issue that should be studied is the possibility of liquefaction and landslide due to high water level. The situation is critical along shoreline and in North West of Bandar Abbas city. There are evidences of landslide in some valley in north of Bandar Abbas. Fig. 2 shows risk of landslide in north of the city and Fig. 3 shows high underground water level which is about 2 meters from the surface. There were many ongoing construction projects when the research was running. Therefore, there were many sources to gather some information about quality of construction. Unfortunately, the quality of construction because of workmanship error and lack of skill and devastating condition of material maintenance is poor. Also because of lack of proper supervision according to building codes, the quality of construction in most sections are not acceptable. Furthermore because of improper condition of maintenance in ports near the shore and humidity and sulfate and chloride attack, corrosion effects occur in most of structures and facilities. This phenomenon is very destructive near the port and lifelines. In addition, adobe structures because of their brittle nature and heavy ceiling without proper lateral load resisting system combined with low quality construction of ties to keep the integrity are considered as vulnerable structures [10]. Moreover, the masonry buildings because of not employing the building regulations and codes are generally vulnerable. Totally, the old texture of the city consists of structures with heavy element and poor foundation and lack of lateral load bearing elements and integrity. Therefore, old parts of the city are considered as very vulnerable regions. It is worth mentioning that such old textures were seen in the Bam earthquake that was the location of many lost lives. Figs. 4 and 5 show improper material or improper usage of material (lack of continuous welding line) [11, 12]. Fig. 6 shows bad maintenance condition. Fig. 7 shows bad condition of protection and corrosion and destruction of material of a deck and pile of the seaport.

Fig. 8 shows improper portioning of frame elements and also improper infill restriction for out of plane forces. Fig. 9 shows lack of control and supervision of the construction project which leads to vulnerable situation in constructions. Masonry buildings are distributed in the city, but their concentration are near the shoreline, and because of not using proper tie elements to connect the walls and ceilings together and maintain the integrity of the masonry buildings [10], it is classified as hazardous type in this area based on building codes of practice. After gathering information, FEMA154 [8] and some designed forms were used to assess building vulnerability Fig. 10.

Fig. 2. Risk of land slide in north of area

Fig. 3. High Level of under ground water

Fig. 4. Buildings with poor structures in hazardous place

Fig. 5. poor Steel constructions

Fig. 6. Improper maintenance of material (bars)

Fig. 7. Devastating condition of seaport

Fig. 8. Lack of restrictions of infill and improper portioning of frame elements

Fig. 9. Lack of integrity in concrete ties connection

Qualitative vulnerability form

Plan and Evaluation Scale	Survivor ______ Address: ______ No.story ______ Year Built ______ Code used to design ______ Total floor area (m^2) ______ Use ______ Structure type ______ Ceiling type ______ Current visual condition: ______ Seismic zone : ______ Accessibility after EQ. ______ Ratio of building heights to passage width Passage width (road) ______
	Photograph or file name

Occupancy					Soil type			
Assembly	School	Governmental	Max No. of Persons		Type I		Liquefaction	
Commercial	Historic	Hospital	0-10	11-100	Type II		Levels of underground water	
Office	Residential	Others	101-1000	1000+	Type III			

Basic assess	
Non-structural vulnerability	
Structural system	
Mid rise	
High rise	
Short	
Vertical irregularity	
Plan irregularity	

Existing problems
Soil effect Construction defect Other parameter

Final vulnerability						
Color	High vulnerability		Medium vulnerability		Very low vulnerability	

3. Data analyzing and vulnerability assessment

Upon conducting field survey, structures were classified based on their overall vulnerability in the studied areas. Table 1 shows the most important factors considered in assigning vulnerability in terms of colors. Each item of this table shows some specifications of vulnerability map and each item was included in the forms with some more details related to that subject. For example, the item of supervision and controlling of building regulations has more details about the presence of irregularity in stiffness or mass distribution in the height or plan of the building. Proposed vulnerability map of this region is shown in Figs. 11 and 12. This map (along with hazard consideration) suggests that rehabilitation of the old general plan with regards to existing urban area is necessary. North and northwestern parts of this city have risk of landslide. There is no protection for foundation against the underground water level [13].

Table 1. Different vulnerability levels classification in this study

Vulnerability levels	Type of vulnerability
Very high vulnerability	Structures without frames or ties
	Structures built on improper soil, in high underground water level regions (With liquefaction and landslide potential)
	Structures without engineered foundations
	Structures constructed with no engineering supervision
	Highly corroded structures
	Structures on sides of narrow passages with no or very little vehicle passing
	Capacity (passage width ≤ 1.5 m) that may be blocked during earthquake)
	Structures placed far from medical or emergency facilities (distance more than 20 km)
	Structures partially tied or framed
	Under construction structures partially affected by corrosion
	Structures constructed with little supervision by practical constructors
	Structures on sides of passages with limited vehicle capacity (1.5 < passage width ≤4 m)
	Structures placed rather far from medical or emergency facilities(distance more than 15 km)
Medium vulnerability	Structures with ties but not fully complying with building regulations
	Structures with little corrosion
	Structures accessible through nearby passages (4 < passage width ≤ 12 m)
	Structures placed within middle range distances from medical and emergency centers (distance more than 10 km)
	Structures with frames or ties, complying with regulations but with some
	workmanship errors
	Structures rather easily accessible through nearby passages (12 < passage width ≤18 m)
	Structures placed rather close to medical and emergency centers (distance more than 5 km)
Very low vulnerability	Structures with frames or ties and comply with up to date regulations
	Structures built on proper soil, in low underground water level regions (No liquefaction or landslide potential)
	Structures without corrosion and high quality of constructions
	Structures easily accessible through nearby passages (passage width >18 m)
	Structures placed close to medical and emergency centers (distance less than 1.5km)

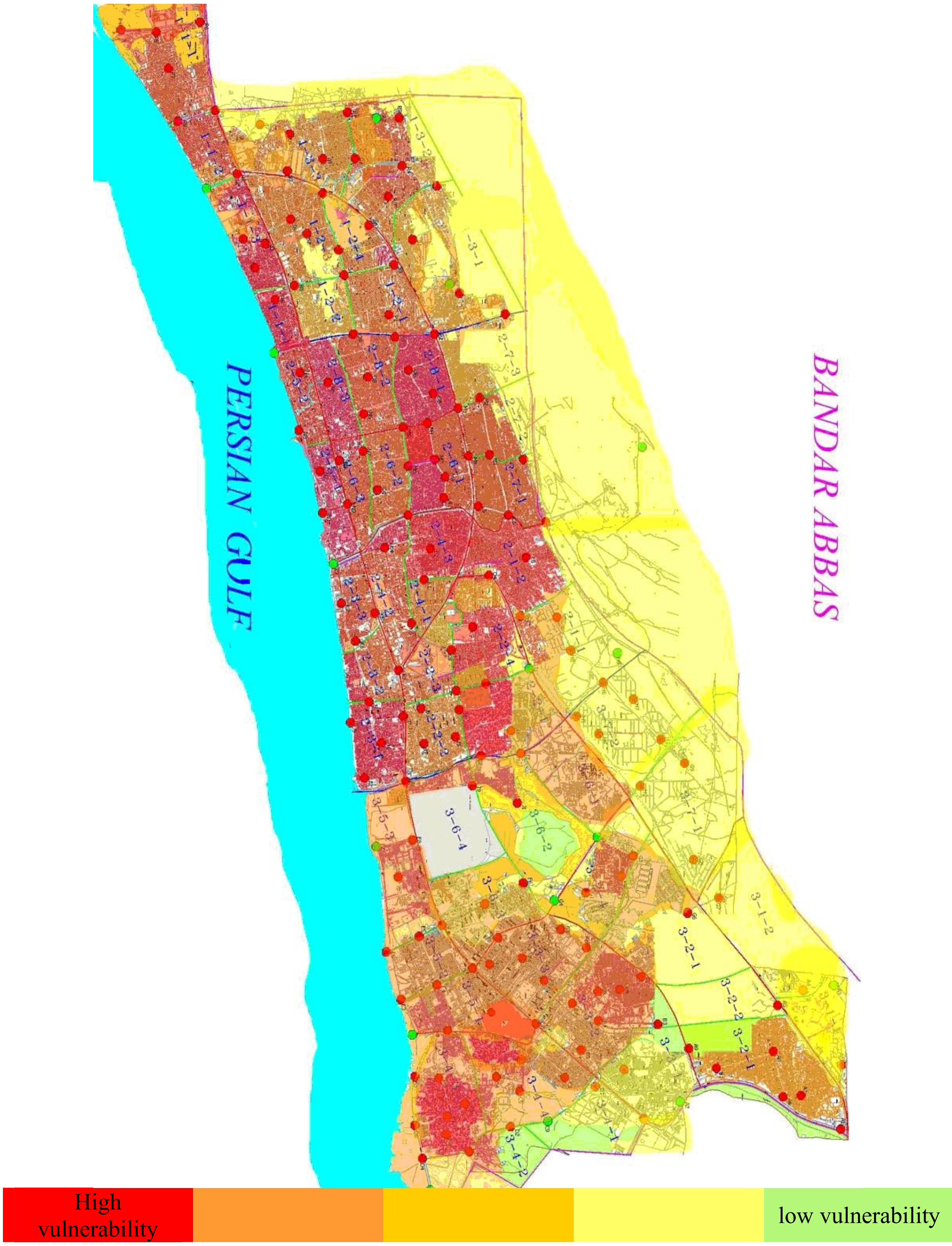


Fig. 11. Recommended seismic vulnerability of Bandar Abbas city

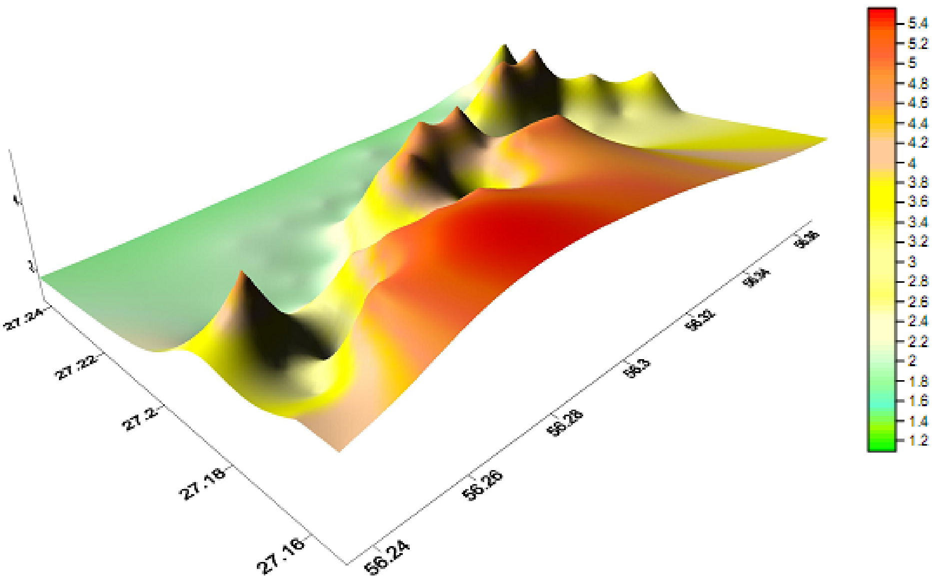


Fig. 12. 3D Seismic vulnerability of Bandar abbas and its vicinity

4. Seismotectonic structure of Bandar Abbas

This region is located at the edge where the Saudi Arabian plate pushes forward towards the Iran plateau and situated on the south plateau of Zagros Mountain. In order to evaluate the seismic hazard of a region or zone, all the probable seismic sources must be detected and their potential to produce strong ground motion must be checked. The major faults in Bandar Abbas region are MZRF, MFF, HZF, ZFF, Zendan-Minab, Giroft-Abzevaran, Chah Shirin, Giroft, Bashagard, Beach Makran, Faarooj, Roodan and Minab [1]. The location of these faults with respect to Bandar Abbas and the focal mechanism of main earthquakes are shown in Fig. 13.

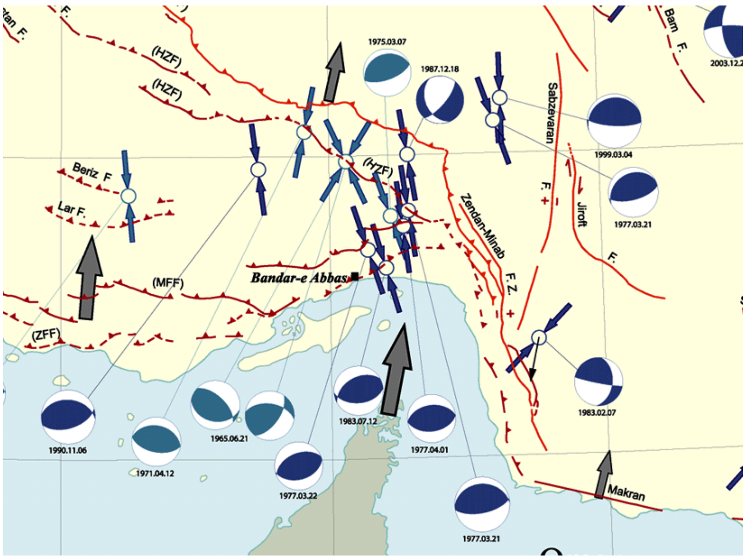


Fig. 13. The active faults of Bandar Abbas [1]

4.1. Seismicity of Bandar Abbas

The seismicity of each region is indicated by the past earthquakes occurred in that region and to obtain the seismo-tectonic properties, a thorough list of each region's earthquake events must be collected and studied.

The information of the earthquakes in radius of 200 km of Bandar Abbas, has been gathered from several references. The reason for the application of probabilistic method and its advantage is the unavailability of our seismic data regarding magnitude and focal depth of earthquakes. The occurrence of destructive earthquakes like the ones that occurred in 1361 AD Gheshm, in 1497 AD Bandar Abbas, and in 1622 AD Bandar Abbas, all show seismic hazards that threaten the region [2].

The types of magnitude scales were not the same. To change these types to one scale, Equation 1, presented by the Iranian Committee of Large Dams IRCOLD [14] was employed to transfer m_b into M_s:

$$M_s = 1.2m_b - 1.29 \quad (1)$$

Where m_b and M_s are body wave magnitude and surface wave magnitude respectively. Seismotectonic and seismicity of Bandar Abbas are shown in Fig. 14.

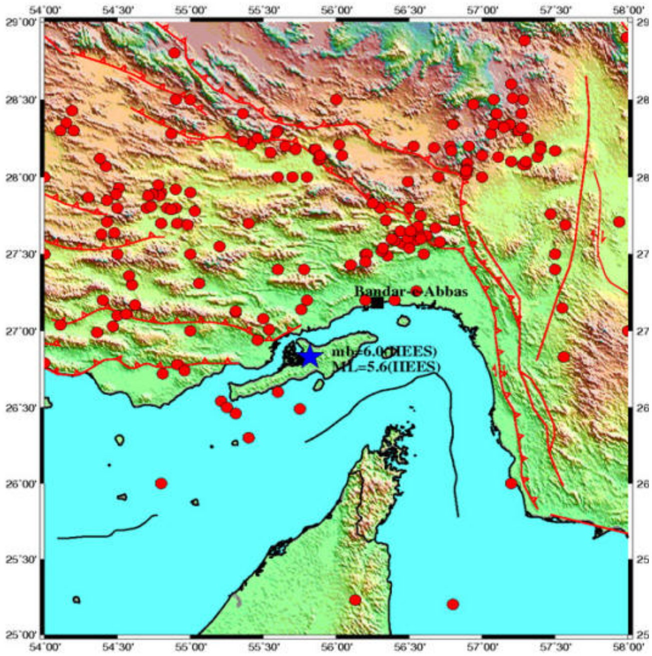


Fig. 14. Seismotectonic and seismicity of Bandar Abbas region [1]

4.2. Seismicity parameters of Bandar Abbas

The evaluation of seismicity parameters is performed based on the seismic data of earthquakes occurred in the region under study and employing probabilistic methods. The seismic catalogue has been collected, assuming that earthquakes follow Poisson distribution. The method which is used to eliminate the foreshocks and aftershocks is the variable windowing method in time and space domains [15].

Due to the very high importance of the seismicity parameters in seismic hazard evaluation, in this study the new Kijko method [16] has been employed which is based on double truncated Gutenberg-Richter relationship [17] and the maximum likelihood estimation method.

In the maximum likelihood estimation method, it is possible to use historic and instrumentally recorded data at the same time.

The annual average occurrence rate of earthquake versus magnitude for earthquakes with magnitude greater than Ms=4.0 in the extent of 200 km around Bandar Abbas is shown in Fig. 15, based on these investigations and the performed calculations with Kijko method, and the results is shown in Table 2.

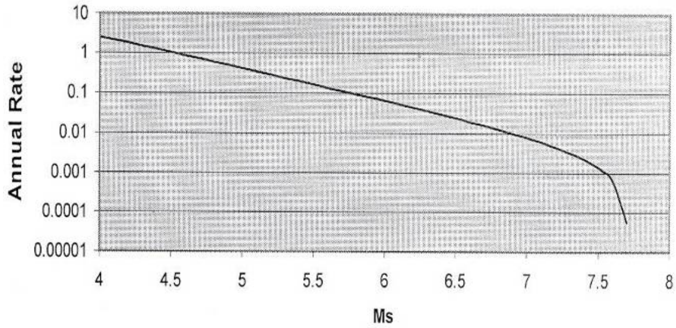


Fig. 15. Annual rates estimated by Kijko method for Bandar Abbas

Table 2. Seismicity parameters of Bandar Abbas obtained by Kijko method

Catalogue	Parameter	Value	Data Contribution to the Parameters (%)		
			Case 1	Case 2	Case 3
Historical and Instrumental Data	Beta	1.82	44.1	15.8	40.1
	Lambda (Ms=4)	2.56	2.3	13.9	83.8

5. Evaluation of horizontal seismic hazard

In order to evaluate PGA for the return period of 475 years, probabilistic seismic hazard analysis method has been used. In this method, seismicity parameters (β, λ) are given to the seismic sources based on the seismicity investigations, then based on earthquake magnitude, distance of epicenter or hypocenter from site and application of an appropriate attenuation relationship, PGA at the corresponding site is evaluated. The relationship between maximum expected magnitude and fault length depends on the understanding of the seismotectonic and geotectonic behavior of the concerned area. Nowroozi [18] has offered Equation 2 after studying over ten severe earthquakes in Iran and observing active faults ruptures.

$$Ms = 1.259 + 1.244 Log(L) \qquad (2)$$

where M_s and L are surface wave magnitude and rupture length in meters respectively.

5.2. Attenuation relationship

Selection of appropriate attenuation relationship is very important in validity and reliability of the analysis results. Therefore, there are some important notes that must be paid attention to for the selection of attenuation relationship. The most important ones are source specifications, magnitude, fault rupture type, distance to the seismogenic sources, geology and topology of site.

Based on the mentioned remarks, in this research four weighted horizontal attenuation relationships, namely, Ramazi [19], 0.3; Ambraseys and Bommer [20], 0.2; Ghodrati Amiri et al. [21], 0.35; and Sarma and Srbulov's [22], 0.15; in Logic Tree method were employed.

5.1. Probabilistic seismic hazard analysis

For the seismic hazard probabilistic evaluation, the software SEISRISK III [23] was utilized to calculate the PGA in the specific hazard level in the structure lifetime. The calculated values can be shown in the form of iso-acceleration lines for the return period of 475 years. In this study the seismic hazard analysis carried out was based on the assumption of an ideal bedrock case and therefore no influence of local soil condition is taken into consideration. Before the calculations, a grid of sites must be considered in the region where seismic hazard analysis is performed. For this purpose a grid of 18*13 is considered.

As a result, our outputs are Peak Ground Acceleration (PGA) with 10 percent probabilities of exceedence in 50-year lifetime of structure. The result of the seismic hazard analysis is graphically shown in Fig. 16.

6. General vulnerability of Bandar Abbas

In order to achieve the seismic vulnerability of Bandar Abbas, vulnerability map of building has been set on seismic hazard map. Therefore the seismicity of each region is indicated by vulnerability of buildings and seismic hazard of region. Intensity of seismic vulnerability has been shown by color and numbers which is explained in Fig. 17.

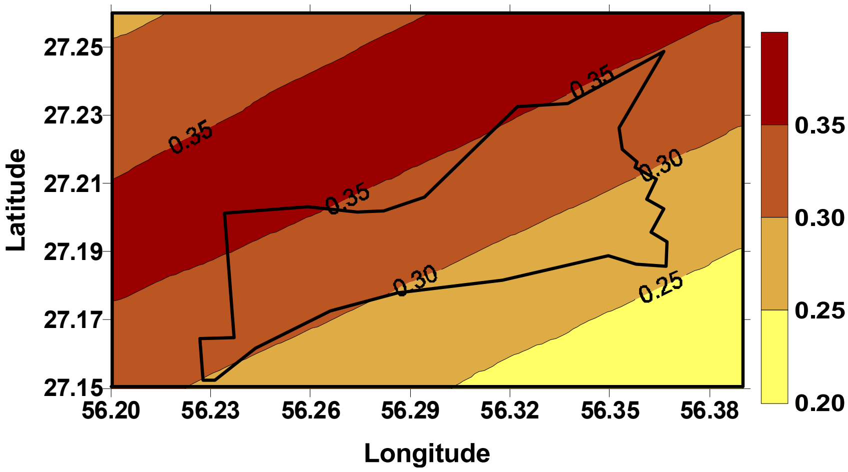


Fig. 16. Horizontal seismic hazard map of Bandar Abbas and its vicinity in using logic tree for 475-year return period and the border of city (thick line)

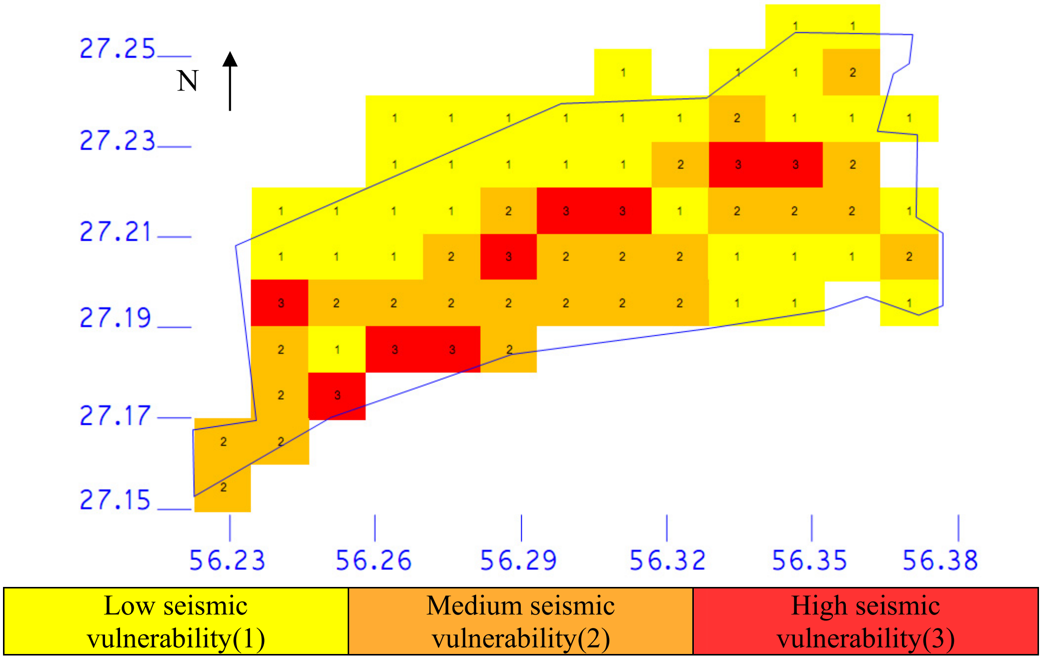


Fig. 17. General vulnerability of Bandar Abbas with horizontal seismic hazard using logic tree for 475-year return period

7. Conclusions

This paper presents seismic hazard of Bandar Abbas based on Peak Ground Horizontal Acceleration (PGHA) for 10 percent probabilities of exceed in a time span of 50 years and vulnerability assessment of Bandar Abbas and its vicinity. The significant results of this study can be summarized as follows:

1. The contour levels of the horizontal acceleration hazard maps showed that the PGHA for 10 percent ranges from 0.205(g) to around 0.38(g)

2. The highest acceleration contours are located in the northern and northwestern parts of Bandar Abbas.

3. The smallest accelerations are expected in southeast of Bandar Abbas.

4. The comparison of the results with the recommended PGA in Iranian Code of Practice for Seismic Resistant Design of Buildings (0.30g) shows that the recommended PGA is lower than what has been achieved in this study for most parts of the region. This PGA can cause major structural damage in important structures and lifeline systems.

5. The highest General Seismic vulnerability is located in some area in the center and southwest of the city.

6. Low General Seismic vulnerability is seen in the north and southeast of Bandar Abbas.

7. Fortunately location with the high Seismic acceleration is not the same as with high Seismic vulnerability.

REFERENCES

[1] IIEES, International Institute of Earthquake Engineering & Seismology, http://www.iiees.ac.ir/.

[2] Ambraseys, N.N., Melville, C.P. (1982). "A history of Persian earthquakes". Cambridge University Press, Cambridge, Britain.

[3] Zare, M., Fatemi, A.A. (2003). "Seismotectonic and earthquake fault hazard investigations in the Hormozgan state region". Pishahangan Amayesh Consulting Engineering Company.

[4] IIEES, (2009). "Provisions for rehabilitation of structures". Second edition, International Institute of Earthquake Engineering & Seismology.

[5] Grünthal, ed., (1998). "European macro seismic scale (EMS98)". Cahiers du Centre Européen de Séismologie,Vol. 15.

[6] FEMA, (1999). "Earthquake loss estimation methodology". Federal Emergency Management Agency, HAZUS.

[7] GNDT, (1986). "Instruzioni per la compilazione de lla sceda di relivamento esposizione e vulnerabilità sismica degli edifici". Gruppo Nazionale per la Difesa dai Terremoti.

[8] FEMA 154, (2002). "Rapid visual screening of buildings for potential seismic hazards". Edition 2, Federal Emergency Management Agency.

[9] BHRC, (2005). "Iranian code of practice for seismic resistant design of buildings, standard No. 2800". 3rd Revision, Building & Housing Research Center, Tehran, Iran.

[10] Moghddam, H. (2002). "Earthquake engineering for earthquake engineers". Sharif University of Technology, Tehran, Iran.

[11] Bargi, Kh. (1995). "Fundamental of earthquake engineering". Tehran University, Tehran, Iran.

[12] FEMA 273, (1997). "Provision for rehabilitation of existing structures". Federal Emergency Management Agency.

[13] FEMA 274, (1997). "Commentary on the nehrp guidelines for the seismic rehabilitation of buildings". Federal Emergency Management Agency.

[14] IRCOLD, (1994). "Relationship between fault length and maximum expected magnitude". Iranian Committee of Large Dams, Internal Report.

[15] Gardner, J.K., Knopoff, L. (1974). "Is the sequence of earthquake in southern California, with aftershocks removed, Poissonian?". Bull. Seismol. Soc. Am., Vol. 64, pp. 1363-1367.

[16] Kijko, A. (2000). "Statistical estimation of maximum regional earthquake magnitude Mmax". Workshop of Seismicity Modeling in Seismic Hazard Mapping, Poljce, Slovenia, Geol. Survey, pp. 1-10.

[17] Gutenberg, B., Richter, C.F. (1954). "Seismicity of the earth and associated phenomena". Princeton University Press, New Jersey.

[18] Nowroozi, A. (1985). "Empirical relations between magnitude and fault parameters for earthquakes in Iran". Bull. Seismol. Soc. Am., Vol. 75, pp. 1327-1338.

[19] Ramazi, H.R. (1999). "Attenuation laws of Iranian earthquakes". Proceedings of the 3rd International Conference on Seismology and Earthquake Engineering, Tehran, Iran, pp. 337-344.

[20] Ambraseys, N.N., Bommer, J.J. (1991). "The attenuation of ground accelerations in Europe". Earthquake Eng. and Struct. Dynam.,Vol. 20, pp. 1179-1202.

[21] Ghodrati Amiri, G., Mahdavian, A., Manouchehri Dana, F. (2007). "Attenuation relationships for Iran". J. Earthquake Eng., Vol. 11, No.4, pp. 469-492.

[22] Sarma, S.K., Srbulov, M. (1996). "A simplified method for prediction of kinematic soil-foundation interaction effects on peak horizontal acceleration of a rigid foundation". Earthquake Eng. and Struct. Dynam., Vol. 25, pp. 815-836.

[23] Bender, B., Perkins, D.M. (1987). "SEISRISK-III: A computer program for seismic hazard estimation". U.S. Geological Survey BULLETIN 1772.