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Warning and Rapid Estimation of Earthquake Damage (WARED) system: A New method for Rapid Determination of Earthquakes Damage and Fatality in IRAN

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Abstract

WARED system is Internet-based software that automatically receives the seismic information from Iran seismic center (ISC) every 10 seconds. The information is processed in a few seconds and damage assessment maps of various parts of the city (such as buildings, hospitals, bridges, etc.) become available, in layered format, to rescue groups through system site. WARED system based on the population exposed to each Peak Ground Acceleration (PGA) level, it estimates the losses from earthquakes in residential areas. This system was implemented in the municipality of Mashhad (North East of Iran) in January 2014. Principles of information processing in this system depend on three main factors including the magnitude and location of earthquakes, the properties of the rocks and sediment the earthquake waves travel through, and the technical characteristics of the buildings (strength, age, type, and geotechnical conditions of soil, etc.). Therefore PGA is used as the most important parameter to assess the damages and fatality occurred. Primary purpose of WARED system is rapid dissemination of earthquake impact assessments for decision-making purposes. This is motivated by the idea that an estimated range of damage and number of deaths will aid in decisions regarding humanitarian response.

Keywords: WARED system, Earthquake damage, Iran earthquakes fatality, peak ground acceleration.

1. Introduction

Earthquakes occur suddenly with little or no warning, during any season and at any time of day. However, in some advanced countries Earthquake Early Warning and Rapid Response Systems are used based on the time difference between receiving S and p waves [1]. But the most important challenge for utilizing early warning systems is the cost of the initial implementation of the system, high maintenance expenses, and very little time between warning and receiving earthquake destructive waves. Unfortunately, a lot of international studies, with the aim of preparing for the earthquake, have been done for the modern cities, while most of the metropolitan cities in the world are without the most basic facilities for urban management in the earthquake. Most of these cities lack the necessary funds for the purchase of expensive equipment of crisis management systems. In these cities, the communication infrastructure (telephone, ...) is very vulnerable, and the interruption in the communication systems increases the human errors in the rescue and relief management levels and its outcome, accordingly, will be the increases in human casualties. The experience of the devastating earthquakes in Iran allowed us to evaluate the crisis management in vulnerable cities from a different point of view.

Many metropolitan cities in the world and Iran including Mashhad are adjacent to active faults. Most of these cities lack modern equipment to react quickly in the earthquakes.

Experiencing Earthquake events in cities of Iran which in most cases occurs due to the lack of real time information indicates the inadequacy of urban management facing Earthquake disasters. In such situations, disorder in the rescue and relief operations has increased the death toll and financial loss.

The main problems of urban management in terms of great earthquakes is the heterogeneous distribution of damage in various parts of the city, unfavourable urban conditions, such as irregular old texture, and lack of strength in buildings, telephone call cut-offs and consequently lack of integration in rescue groups [2]. However, most of the major cities in the world are without modern equipment for real-time assessment of the damage caused by the earthquake and disaster management. In such circumstances, a system with low cost and quick return and an acceptable error rate in management decision is of particular importance.

WARED system has been designed for earthquake crisis management in non-prepared cities that lack the financial ability to implement Earthquake Early Warning and Rapid Response Systems. Unsystematic development of cities and lack of financial resources has created complicated conditions in case of natural disasters such as earthquakes. Thus, the occurrence of a strong earthquake in such cities will bring human tragedy. In such situations, due to lack of necessary information (PGA, Soil Amplification Effects, etc.), early damage assessment seems impossible using conventional methods. WARED System measures all parameters needed to evaluate damage indirectly and through simulation. The system having low cost, management application and acceptable error can be implemented in many cities in Iran and throughout the world. The system calculates PGA values through Ground Motion Attenuation Model, allowing quick damage estimation in non-prepared and high earthquake risk cities without much spending. Although this system is not a substitute for Seismic Monitoring and Rapid Response System, it has the ability to send the necessary information after the earthquake in golden time to lead the rescue groups.

2. Warning and Rapid Estimation of Earthquake Damage (WARED) system

WARED System was designed with the aim of earthquake disaster management in unprepared cities who lack the financial ability to implement rapid response and early warning systems. The WARED system has four main indicators which makes it different from other systems.

1- Ability to work with minimum information (magnitudes and locations of earthquakes). 2. No need to install expensive equipment (Accelerograph). 3. The operationalization capability in a short time (6 months). 4. Localization capability for the complex and chaotic conditions prevailing in unprepared cities [3].

WARED system was designed by Tous Knowledge-based Researchers for Natural Events Company (TRNE) and was used as a pilot project in the Municipality of Mashhad (North East of Iran) in January 2014. On April 16, 2015 the first specialized maneuver of earthquake disaster in the Iran water industry was performed by under the supports of WARED system in the city of Mashhad. The maneuver was conducted with the participation of 7 provinces of Tehran, Khorasan, North Khorasan, South Khorasan, Golestan, Mazandaran, Semnan and Yazd. Several different Earthquake damage scenarios, was created through WARED system in this maneuver. Then relief groups, while receiving the information of damaged areas through the website, SMS, and Email, were dispatched to the affected areas. The successful performance of the system led to the following three new missions to be put on the agenda.

1. covering water transmission plants and network in Tehran province.
2. covering North Khorasan Province reservoir dams (North East of Iran).
3. organizing people volunteer organizations (PVOs) in Mashhad in the case of earthquake disaster.

3. WRED System mechanism

WARED system is Internet-based software that automatically receives the seismic information from Iran seismic center (ISC). The information is processed in a few seconds and damage assessment maps of various parts of the city (such as buildings, hospitals, bridges, etc.) become available, in layered format, to rescue groups through system site. This system is a successful experience of natural disaster management system that has been installed in the Mashhad Municipality (North east of Iran) for the first time. The system, assessing the damage and fatality caused by the earthquake, sends real-time information to the urban management and search and rescue teams in earthquake emergencies. WARED system performs receiving, processing and transmitting information through following six steps (Fig. 1).

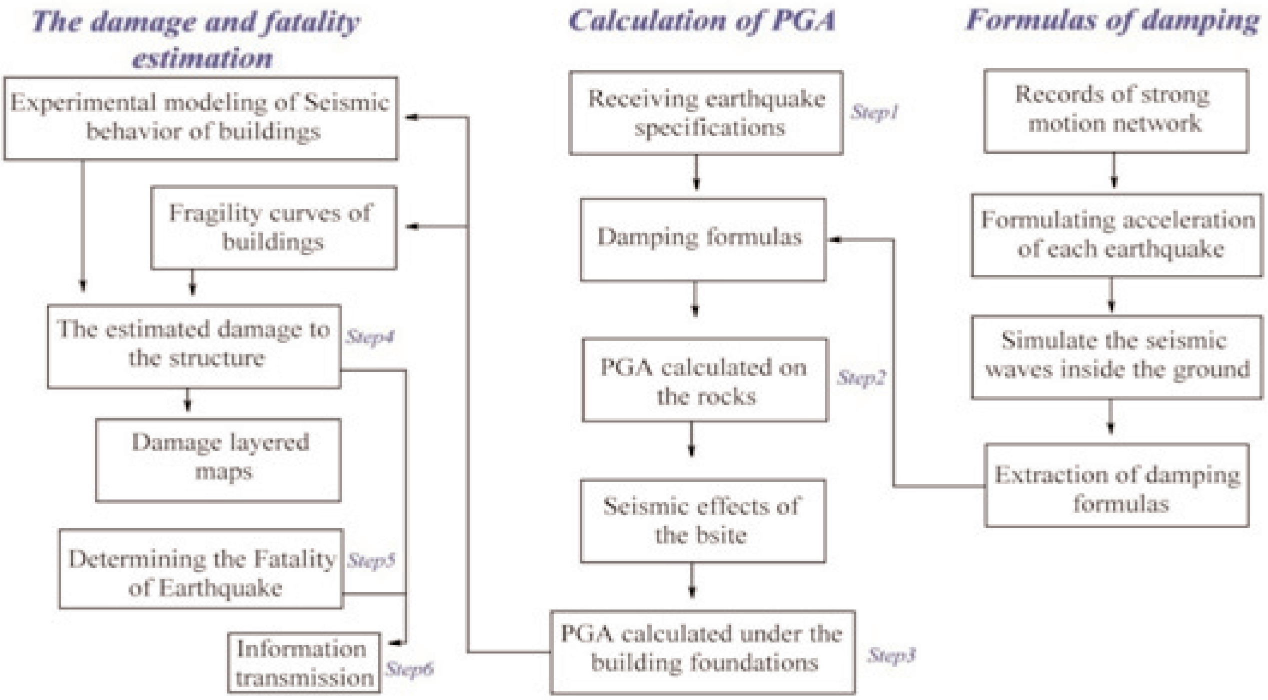


Figure 1. Framework of WARED.

3.1. Receiving the information (Step 1)

WARED system automatically receives the earthquakes data from the Iran seismic centre every 10 seconds. This information includes time, location, size and depth of the earthquakes.

3.2. Simulation of earthquake waves in the Earth's crust (Step 2)

The parameters of earthquake ground motions that have the greatest importance for buildings are: the duration, frequency, displacement, velocity and most importantly acceleration) and of the ground motion. In WARED system, Peak Ground Acceleration Prediction Model (PGAPM) in the Earth's crust is performed by Iran Strong Motion Network. This network was established in 1973 and more than 9,000 accelerogram have been recorded so far with present 1144 strong motion network devices across the country (www.bhrc.ac.ir). WARED system, with the help of this invaluable information package, simulates the seismic waves (Fig. 2). simulation of wave behaviour within the earth's crust earthquake with a view to calculate the peak ground acceleration (PGA), with the help of the simulation software system outside the system environment and with an acceptable decision in a managerial decision. Simulated parameters are encoded in the form of lowering and coded on the system. To evaluate the accuracy of calculations, specifications of past earthquakes are loaded on the system. The results of calculations are compared with the results of the earthquake recorded by the strong motion network.

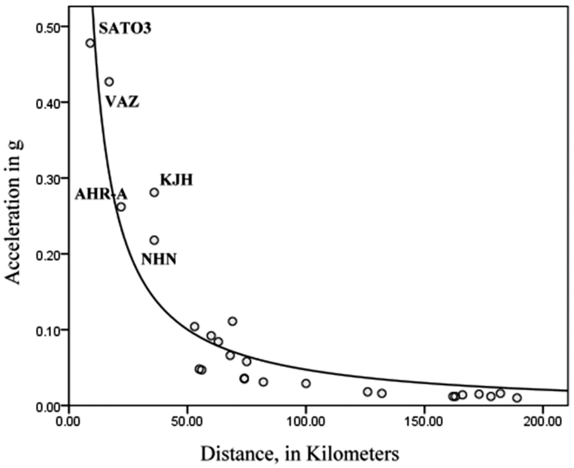


Figure 2. Strong motion acceleration diagram recorded by stations around the epicentre of the Varzeqan earthquake in 2009.

In this system, a total of 771 data points from 27 Iran shallow crustal earthquakes with focal depths less than 20 km were utilized. Table 1 presents these events with relevant information on their magnitude (Mn), focal depth, epicenter coordinates, and fault mechanism. Also listed is the breakdown of record numbers used from each event. The events gathered from the Iran Strong Motion Network (ISMN) database. The distributions of earthquake data with respect to magnitude (Mn) and PGA plot against fault distance are shown in Fig. 3.

The current set includes data recorded within 350 km of the earthquake faults from events in the magnitude range of 4 to 7.5. The data used in the analysis represent main shocks only. Fig. 4. plots the distribution of earthquake data with respect to VS30 measurement at

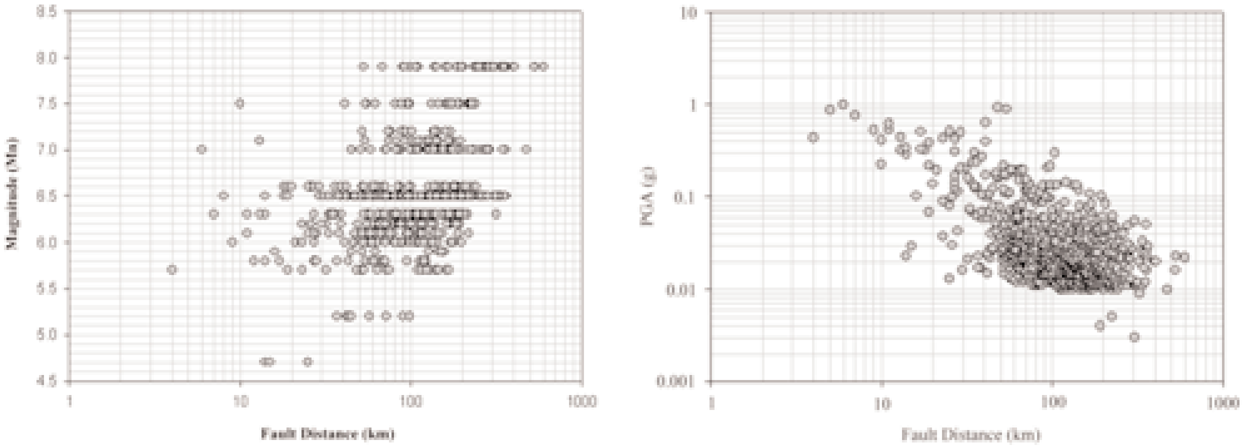


Figure 3. Earthquake data distribution with respect to moment magnitude (left) and PGA (right).

Table 1. List of Iranian events used in development of attenuation relationship.

No				Depth		Epicenter Coordinates		
	Event	**Date**	**Faulting**	**Mw**	**(km)**	**Latitude**	**Longitude**	**Number of Data**
1	Tabas	1978	Reverse	7.4	9	33.37	57.44	9
2	Karizan	1979	Reverse	6.7	3	34.03	59.81	10
3	Koli	1979	Strike-Slip	7.1	10	34.05	59.63	13
4	Sirch	1981	Reverse	7	11	29.99	57.77	12
5	Manjil	1990	Strike-Slip	7.3	18	37.001	49.21	22
6	Zangire	1994	Reverse	5.7	8	28.96	52.61	10
7	Sarin	1997	Strike-Slip	6	12	37.99	48.15	24
8	Ghien	1997	Strike-Slip	6.9	10	33.83	59.83	24
9	Garmkhan	1997	Reverse	6.4	14	37.71	57.49	14
10	Golbaf	1998	Reverse	6.2	10	30.16	57.62	10
11	Kare-Ba	1999	Strike-Slip	6.1	2	29.49	51.89	27
12	Changore	2002	Reverse	6.4	12	35.66	48.92	78
13	Bam	2003	Reverse	6.6	7	29.04	58.33	27
14	Kogor	2004	Reverse	6.4	16	36.28	51.61	148
15	Geshm	2005	Reverse	5.7	8	26.78	55.90	12
16	Zarand	2005	Reverse	6.5	10	30.80	56.77	31
17	Silakhor	2006	Strike-Slip	5.9	9	33.69	49.00	29
18	Kahak	2007	Strike-Slip	5.9	14	34.54	50.91	51
19	Torbat	2010	Strike-Slip	5.9	20	35.28	59.26	21
20	Rigan	2011	Strike-Slip	6.1	12	28.15	59.00	12
21	Nyshabour	2012	Reverse	5.2	8	36.29	58.84	8
22	varzegan2	2012	Strike-Slip	6.2	4	38.45	46.75	74
23	varzegan1	2012	Strike-Slip	6.1	9	38.52	46.86	53
24	Shombe	2013	Reverse	6	11	28.46	51.62	20
25	Mormori	2014	Reverse	6	10	32.62	47.67	21
26	Golbaf	2015	Reverse	4	10	30.00	57.67	3
27	Kshmar	2015	Strike-Slip	5.4	10	35.30	58.43	8
								Total= 771
* Data source: Iran Strong Motion Network (ISMN)								

each station. It should be noted that approximately half of the stations in our database have measured shear-wave velocity profiles, while the rest do not.

Ground Motion Attenuation Model in WARED system was designed to aim at calculating the PGA in rock (Eq. 1). The first part of the equation takes Mn Magnitude and style of faulting scaling into consideration. The second part of the equation represents attenuating rhythm of PGA with distance from the fault (Equation 1). The third part shows the regional correction factor. Since WARED system receives earthquake information online from Iranian Seismological Center (ISC), attenuation relations used in the system is calibrated with an Mn magnitude. The specification of earthquakes (latitude, Mn magnitude and focal depth) is received through Iranian Seismological Center (ISC) every moment. The model uses predicted Peak Ground Acceleration

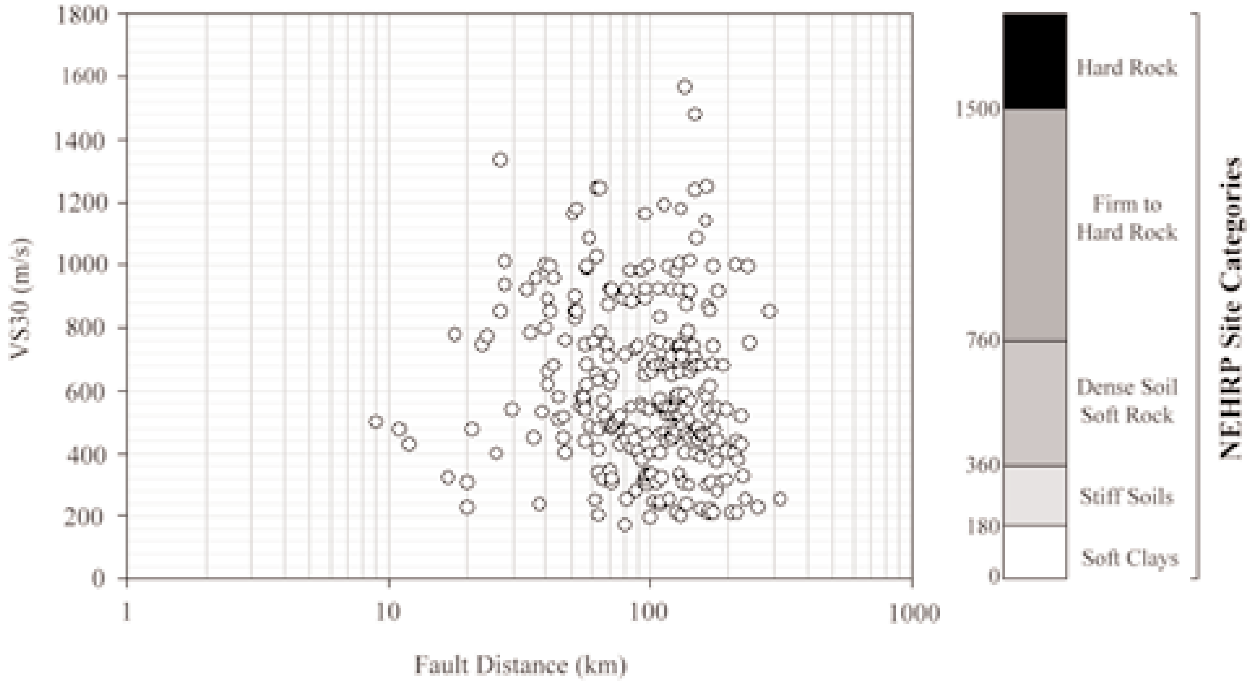


Figure 4. Earthquake data distribution with respect to VS30 and its comparison with NEHRP site categories.

Prediction Model to calculate PGA values on a rock in different parts of the city (Fig. 5).

$$PGA = In [(a_1 \arctan (Mn + a_2) + a_3) 1.14] - 0.5 In [(1 - R / b_1 Mn + b_2)^2 + 4 [b_3 \cos (b_4 (Mn + b_5)) + b_6]2 R / (b_1 Mn + b_2)] + Lp$$

R = closest fault distance

Mn = Magnitude

Lp = Regional correction factor

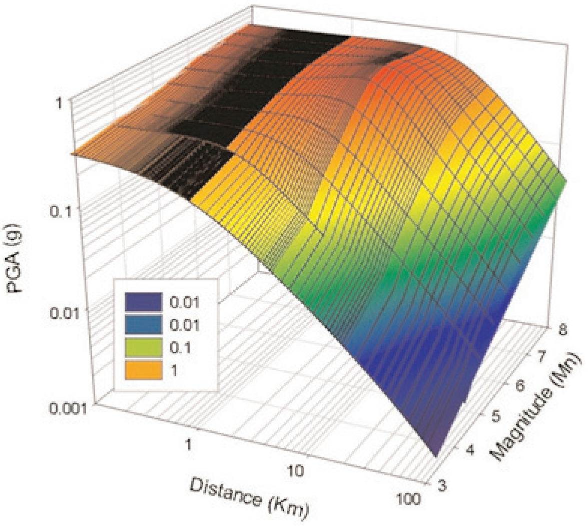


Figure 5. Three-dimensional attenuation surface for earthquakes of north east of Iran.

3.3. Modeling the earthquake wave behavior under the building foundations (Step 3)

Earthquake intensity at a given site is attenuated or increased by local site conditions. Two significant factors that determine amplification are soil and topography. Urban (2002) [4] considers that site conditions are perhaps the most complex subject to model within the field of earthquake hazard. The physical-mechanical properties of soil (i.e. cohesion, structure and depth of the superficial layers) influence the vertical transmission of the wave. In general, the intensity of ground motion is higher in unconsolidated soft soils than in firm soil or rock. According to Finn (1994) [5], damage patterns in Mexico City after the 1985 Michoacán earthquake demonstrated conclusively the significant effects of local site conditions on the seismic response of the ground. Peak accelerations of incoming motions in rock, generally less than 0.04 g, were amplified about five times on the clay soils of the old lakebed, with devastating effects for structures with periods close to site periods. Similarly, Housner (in Finn 1994) [6] points out that in the 1989 Loma Prieta earthquake major damage occurred on soft sites in the San

Francisco-Oakland region, where the spectral accelerations were amplified two to four times above adjacent rock sites. Similarly, the research of Rebez, Peruzza et al. (1999) [7] demonstrated that soil condition was a first-order factor influencing the level of the expected shaking, with an average increase of about 0.2 g for the prediction related to a 475-year return period for Italy, when passing from rock to soft soil.

Earthquake waves are supported by significant thickness of very weak soils before reaching the surface. Changes in the specifications of earthquake waves, when passing through different soils, have enabled some scholars to put local soil conditions in the first place when assessing the vulnerability of structures against the earthquake. Different conditions alluvium thickness, physical and mechanical properties of the soil and underground water levels have major impact on the resonance of the acceleration of the earthquake on the ground surface. In addition, earthquakes with different magnitudes cause various seismic site effects in one place [8].

With regard to the effect of different soil magnification in different parts of the city, the vulnerability of different areas of the city in terms of the earthquake will be different. Therefore, taking into account the effect of wave's magnification, resonance of the earthquake is calculated (Fig. 6). WARED system, with the help of geotechnical speculations in different parts of the city, calculates the effects of alluvial on the seismic waves and uses them in the final processing. In addition, using experimental modeling, it can calculate and use the correction index of the seismic effect of a location in earthquakes with different magnitudes in data processing [3].

3.4. Assessing the damage caused by the quake (Step 4)

In WARED system, the estimation of damage from the quake to buildings in the old urban texture, the semi-skeleton buildings and other non-structural components is based on an empirical model. But assessing the damage from the quake to different engineering structures is done with the help of the fragility curves [9]. In this way, the existing structures throughout the city are classified into various categories according to the kind of materials, engineering design, the number of stories, etc., and some exemplar maps are modelled for each category according to their seismic behaviour to the earth-

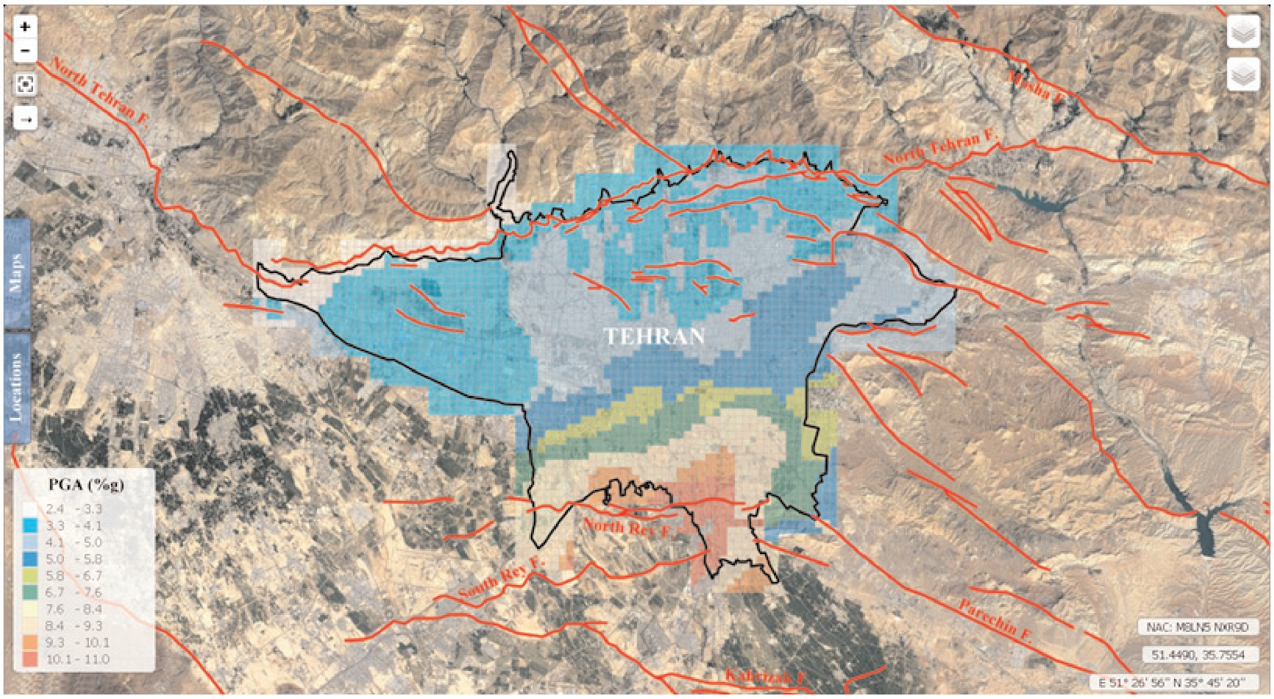


Figure 6. Zoning map of peak ground acceleration (PGA) based on simulation of a hypothetical earthquake South East of Tehran (WARED system).

quake (Fig. 7). The resulting maps are also produced in the form of maps of equal damage to old texture, engineering structures, industrial structures, subway network, and energy transmission network.

Undoubtedly, this evaluation has been of a significant error. But it seems very beneficial as an early and initial report of the volume of potential damage caused by the quake. These maps improve the management of the rescue operation through presenting a logical perspective of the volume of the potential damage caused by the quake. Undoubtedly, urban management, when receiving such field information, can correct the initial assessment of the damage.

3.5. Determining the Fatality of Earthquakes (Step 5)

Examination of Iran earthquake fatality data reveals that 87 percent of the total deaths is related to shaking (not including deaths due to secondary effects such as fire, tsunami, liquefaction or landslide). Seventy-five earthquakes in Iran caused a total of 161,000 fatalities, whereas 62 deadly earthquakes in Indonesia have killed 11000. The United States has experienced 18 fatal earthquakes, but remarkably they caused only 270 deaths, averaging 15 deaths per event during the last 100 years [10]. but the number of deaths Iranian earthquakes in any single event is quite large compared to other countries. Earthquake fatality and exposure data of past earthquakes in general provide a useful basis for developing Iran fatality rates that can be used for future earthquake fatality estimation

The empirical model for estimation of death toll presented in this paper (Eq. 2), has been prepared using 98 deadly earthquakes in Iran during the years 1900 to 2016. The model was called Iran earthquakes fatality rate (IEFR). In this model, the earthquake fatality rate is defined as total killed divided by total population exposed at specific PGA level.According to this model, the mortality rate of earthquakes to is dependent on 4 parameters a, b, c, d. In this equation, R represents the mortality rate of the population exposed to a specific PGA level. The scope of application of this equation is PGA 40 to 100 (% g).

Then with the help of equation (3), the expected fatality for the population exposed to a specific PGA level

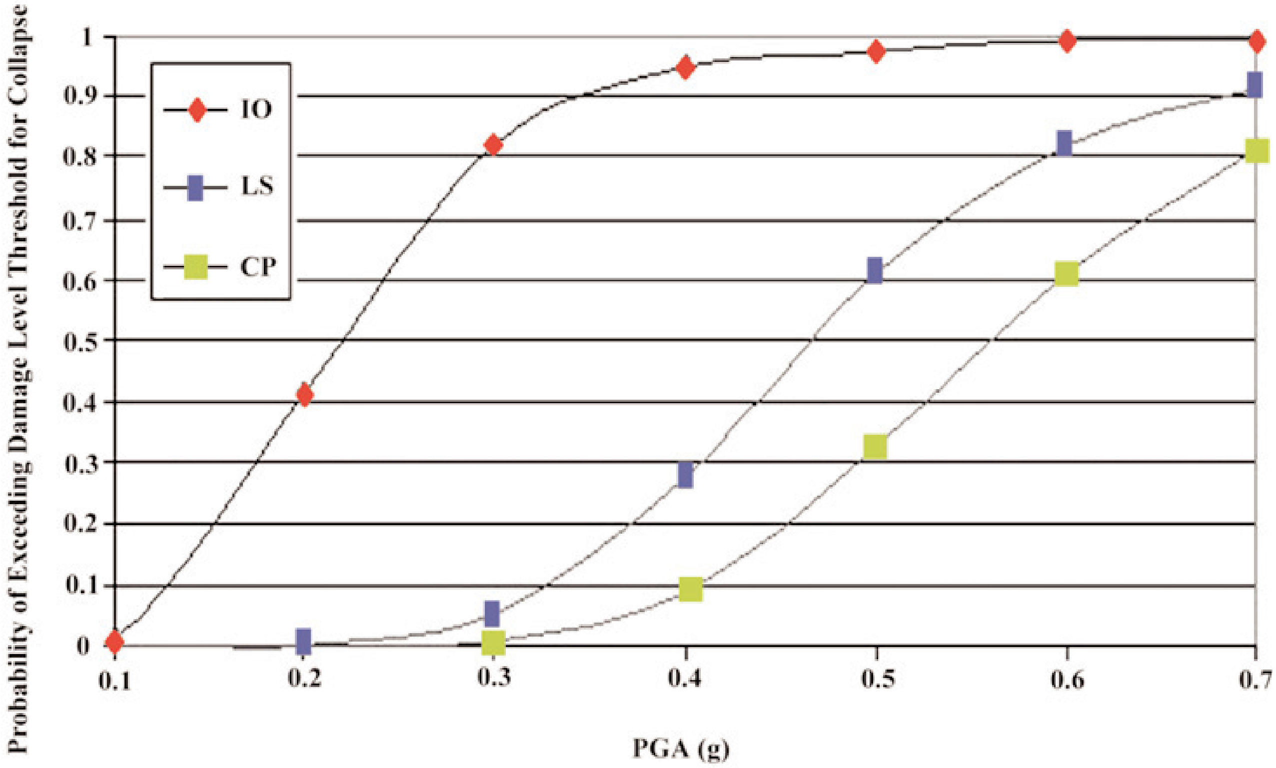
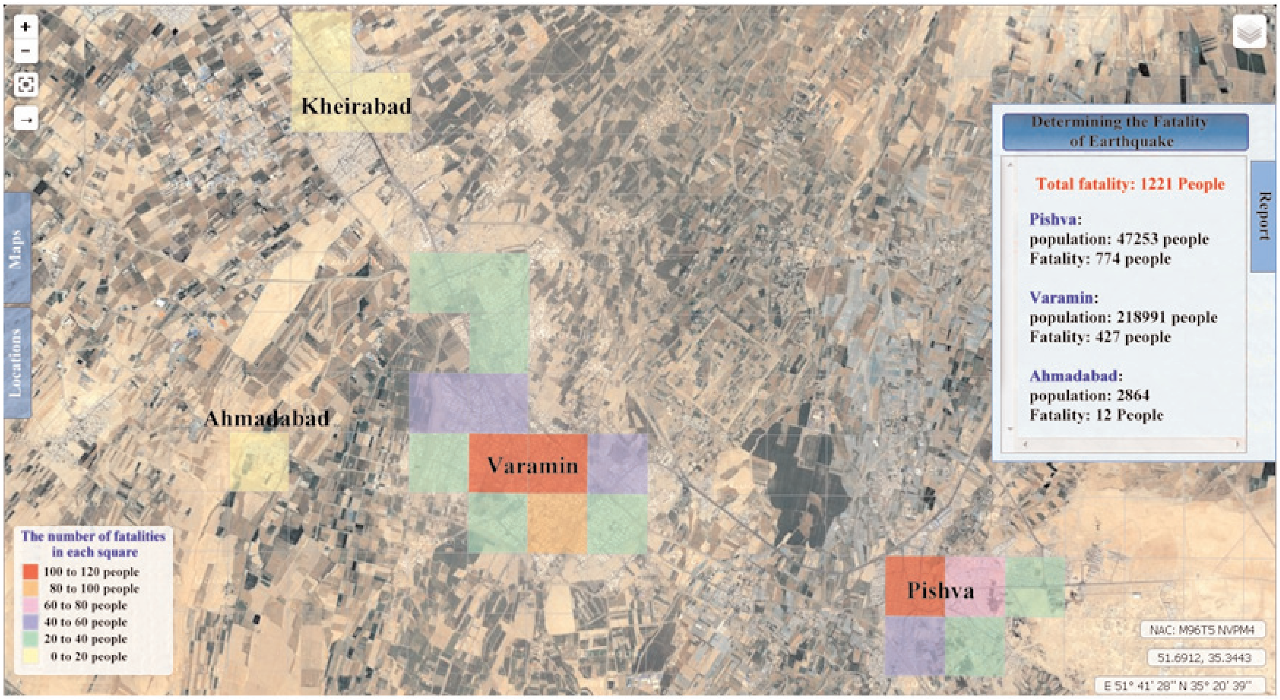


Figure 7. 3-storey buildings fragility curves with cross-braced steel in Mashhad
IO =uninterrupted usability LS= life Security CP= breakdown threshold



Determining the Fatality of Earthquake

Total fatality: 1221 People

Pishva:
population: 47253 people
Fatality: 774 people

Varamin:
population: 218991 people
Fatality: 427 people

Ahmadabad:
population: 2864
Fatality: 12 People

Figure 8. The estimated fatality rate from a hypothetical of magnitude 6.2 on the Richter scale in densely populated areas in Varamin and Pishva South East of Tehran (WARED SYSTEM).

is calculated. In this equation, F represents demographic fatality exposed to specific PGA level, R is mortality rate in this area, and E shows the population exposed to specific PGA level in this area.

$$F = R * E$$

In order to estimate the total number of fatalities from any given earthquake, we need to find a population exposure at each PGA level and a fatality rate associated with the PGA (Fig. 8). Therefore, the sum of the fatality of population exposed to each of these PGA levels specifies total expected mortality arising from an earthquake.

3.6. Information transmission (Step 6)

In an earthquake emergency, WARED system, after blowing the sirens, sends the necessary information to rescue squad and voluntary groups via SMS and Email. In addition, these people, using personal usernames and passwords, can enter the system site and observe the evaluation of damage caused by the earthquake to different parts of the city. Rescue groups are also able to record their field observations of actual damages and casualties caused by the earthquake on the system. The detailed reports of damage and casualties in the earthquake are available to urban management and other aid workers moment by moment.

4. Conclusions

Using Ground Motion Attenuation Model, soil amplification effects and simulation of structures behaviour, WARED system estimates the probable damage caused by earthquake 5 to 10 minutes after its occurrence. Using Peak Ground Acceleration Prediction Model (PGAPM) for PGA calculation makes the earthquake quick damage estimation in non-prepared cities possible without much spending. This system evaluates early physical, human and economic damage caused by the earthquake and sends the information package to different parts of the urban management, thus leading to the integrity of the urban management in case of an earthquake. Moreover, the system maximizes the use of the facilities, equipments and people in the crisis caused by the quake through channelling the dispatch of aid groups. WARED system provides opportunity to quickly and approximately assess the potential disaster of any earthquake in Iran through one empirical model's quick estimation of deaths caused by the earthquake.

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