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Seismic loss assessment: the case study of the power distribution network in Arak city, Iran

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ABSTRACT

Vital infrastructures have, nowadays, a high level of importance in urban areas. Any disruption in one of the infrastructures can cause severe impacts on inhabitants and consequently can affect the other infrastructure systems. In this regard, the electricity grid is considered to be one of the most critical infrastructures, and it has been performed vulnerable to natural hazards, specifically in past earthquakes. Iran is located in a high seismic activity region. Therefore, in this study, the seismic vulnerability of the power distribution network in Arak city has been comprehensively investigated. The power grid has three sections consisting: the electricity generation, transmission, and distribution. In this study, a seismic risk analysis was carried out on its distribution section. The obtained results show that the seismic hazard in the north-eastern part of Arak city is at the lowest level, and in the south-west region, it is at the highest level. Then, the potential damage to the network and the possible financial losses have been calculated. It was revealed that the 315 KVA transformer substations, 615 KVA transformer substations, and finally transmission lines, are at the highest seismic risk of financial damage. According to the obtained results, the probable financial losses for a return period of 475 years event for the 315 KVA transformer substations, the 615 KVA transformer substations, the transmission lines with 120 mm and 70 mm aluminum wires are, respectively, 22300000, 5717000, 270000, and 700000 U.S. dollars.

Keywords: **Probabilistic Seismic Hazard Analysis, risk-mitigation, decision making, earthquake loss estimation**

1. INTRODUCTION

Since the beginning of creation, the human being has been confronted with the issue of natural disasters, and has tried to control their effects while protecting his life from these dangers. Among natural disasters, earthquakes have unique characteristics, and in the last century, earthquake crisis management has become more critical. In recent years, on average, every five years, severe earthquakes have occurred in Iran with considerable financial and personal injuries. Iran is one of the countries where the earthquake is associated with high death tolls. The need for electricity, especially in critical situations following natural disasters such as earthquakes, is essential to carry out emergency and crisis management activities in different sectors. Therefore, there is a need for seismic evaluation of different parts of power distribution networks and their improvement in earthquake safety. The power distribution network is a vital infrastructure, and since every vital infrastructure affects a set of urban equipment, it also has a direct and indirect impact on other vital infrastructures. In fact, paralyzing one vital infrastructure causes other vital infrastructures to malfunction and consequently not able to supply the necessary power to stakeholders. Vanzi (1996) presented a model to test the seismic reliability of electric power networks. Subsequently, Rose et al. (1997) proposed a method for estimating regional economic losses for earthquake damages to power lines in which their method was further used by a number of researchers [1- 5]. Chang and Wu (2011) studied the electricity grid in China and found that most of them are near critical points and also vulnerable to external disturbances such as hurricanes and earthquakes that may cause power outages [6]. Giovinazzi et al. (2017) exemplified the potentialities of Decision Support Systems (DSSs) created in the framework of the EU-funded project, which enabled them to perform a risk assessment for Critical

Infrastructures (CI) when subjected to different natural hazards, including earthquakes [7]. Poulos et al. (2017) computed the seismic risk of electric power systems, and their methodology was applied to the electric network in north Chile, which had been used to estimate the Energy Not Supplied (ENS) and the Energy Index of Unreliability (EIU) [8]. Salman and Yue (2018) presented a framework for investigating the effectiveness of multi-hazard risk mitigation strategies for electric power systems subjected to seismic and hurricane wind hazards [9]. Wang et al. (2018) presented an approach for estimating the seismic performance of large-scale electric power systems subjected to spatially correlated earthquake ground motions. The network flow theory has used to model the power flow allocation over the grid components, and a stochastic ground motion model had been employed to represent the spatial characteristics of earthquake excitations [10]. Dunn et al. (2018) proposed a fragility curve for assessing the resilience of electricity Networks Constructed from an Extensive Fault Database [11,12]. Brennan and Koliou (2020) demonstrated the ability of the retrofit approach of adding flexural stiffeners on the transformer cover plates to reduce earthquake-induced economic losses compared to the as-installed conditions [13]. Farahani et al. (2020) Investigated the seismic risk of the Asaluyeh city urban gas distribution network by regarding the all geo-seismic hazard using HAZUS methodology [14]. Liu et al. (2020) proposed a seismic risk assessment framework for electric power distribution systems considering both the network topology and the functional vulnerability of distribution substations. Implicit Z-bus method was applied to solve the distribution system power flow and evaluate system serviceability [15].Seismic hazard analysis is a quantitative estimate of the hazards of earthquakes in a particular location. In hazard analysis, parameters such as distance, magnitudes, Ground Motion Prediction Equations (GMPE), local soil conditions were incorporated, and consequently ground motion intensity, (e.g. Peak Ground Acceleration (PGA)) is calculated at the desired locations. The Probabilistic Seismic Hazard Analysis (PSHA) has been used throughout this study, considering the epistemic uncertainties [16]. Since the earthquake and its related phenomena are uncertain processes, the PSHA approach offers more conclusive results, but it is apparent that the volume of data and its execution time will be greater than the deterministic approaches [16]. In this study, first, PSHA for Arak city in Iran (Fig 1) was carried out. Then the determination of the high-risk and low-risk seismic points has been clarified. Finally, the potential damage to the network and the possible financial losses through the Hazus guideline were conducted [17].

Figure 1. Location of Arak city in Iran.

2. MATERIALS AND METHODOLOGY

2.1. PSHA FOR THE SITE UNDER CONSIDERATION

In this section, a probabilistic seismic hazard assessment is performed for Arak city using the Crisis analytical software [18], and the results are then used as inputs to the Hazus technical manual [17].To perform the seismic hazard assessment of Arak city, first, the seismic catalogue of earthquakes with a radius of 150 km was gathered from the International Institute of Earthquake Engineering [19] for moment magnitude greater than 4 [19]. All the magnitude types were converted into moment magnitude by using available empirical relationships [20]. The foreshocks and aftershocks were eliminated by employing the Gardner and Knopff approach [21].

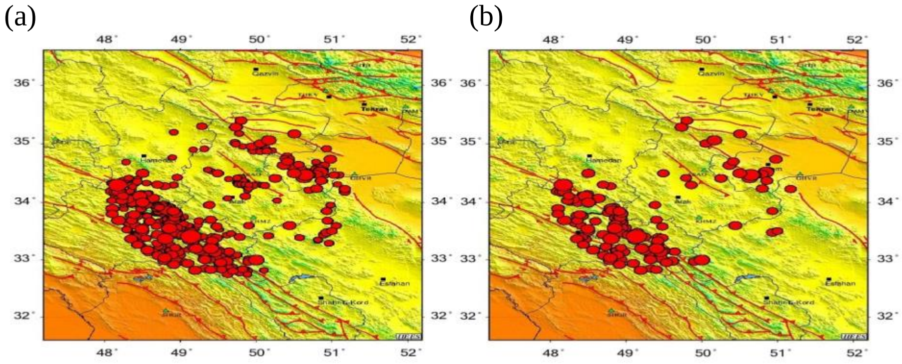

Figure 2. The epicentres and magnitudes of earthquakes in the Arak region. a) Before eliminating magnitudes less than 4, b) After removing magnitudes less than 4 [19].

In the Crisis software platform, the scope of analysis in terms of latitude and longitude has been defined. Then this area has been refined by using a rectangular mesh. In this study, a rectangular range of latitude 31.895 ° to 36.305 ° and longitude of 46.73 to 53.22 with a mesh size of 0.05 ° are considered. In the current study, the studied region is classified with three area sources, as seen in Figure 3. The Gutenberg-Richter relationship has been used to calculate the distribution of the magnitudes [22]. As shown in Table 1, the mean seismic activity λ, the β-value of the frequency magnitude Gutenberg-Richter relation, and coefficient variation of β values obtained from the Kijko method [23].

Table 1. Results of beta (β) and lambda (λ) values obtained from Kijko method [23].

Seismic Region	β	λ	Coefficient variation of β
1	1.46	0.62	0.11
2	2.28	0.24	0.16
3	2.05	0.24	0.16

GMPEs are the most important components that significantly affect PSHA results [24]. The selection, and the determination of the contribution weight to assign to each of them, is a fundamental component of any seismic hazard analysis. The growing quantity and quality of ground-motion information on recordings in different catalogues have resulted in numerous regional and worldwide GMPEs through recent decades [25]. It was demonstrated that the uncertainty corresponding to the selection of a given GMPE influences the hazard results more than other aspects of seismicity modeling [26]. It is better to use indigenous equations to predict the ground motion, which is largely based on the country's seismic data, as well as regional equations based on regional data and global equations developed on the basis of worldwide data. In the present study, the following ground motion prediction equations are used, as seen in Table 2, with equal weights of 0.2.

Table 2. GMPEs used in the current study.

GMPE name	Abbreviation
Boore, Stewart, Seyhan and Atkinson (2014) [27]	**BSSA14**
Abrahamson, Silva and Kamai (2014) [28]	**ASK14**
Chiou and Youngs (2014) [29]	**CY14**
Campell and Bozorgnia (2014) [30]	**CB14**
Zafarani et al. (2014) [31]	**ZAF14**

PSHA has been performed for the 475 and 2475 years return periods. The results of peak ground acceleration can be seen in Tables 3 and 4. According to the hazard map (Fig 3), Arak city area is divided into 4 areas (Fig 4).

Table 3. The results of peak ground acceleration(PGA) in return period of 475

Region	PGA Hazard (475 Years)					Average
	ASK14	BSSA14	CB14	CY14	Zaf14	
1	0.142	0.185	0.196	0.166	0.257	0.189
2	0.153	0.191	0.202	0.175	0.263	0.196
3	0.165	0.202	0.215	0.189	0.27	0.208
4	0.181	0.213	0.232	0.205	0.277	0.221

Table 4. The results of peak ground acceleration(PGA) in return period of 2475

Region	PGA Hazard (2475 Years)					Average
	ASK14	BSSA14	CB14	CY14	Zaf14	
1	0.257	0.335	0.362	0.325	0.4	0.335
2	0.271	0.351	0.372	0.349	0.41	0.350
3	0.301	0.374	0.408	0.376	0.428	0.377
4	0.328	0.399	0.447	0.416	0.445	0.407

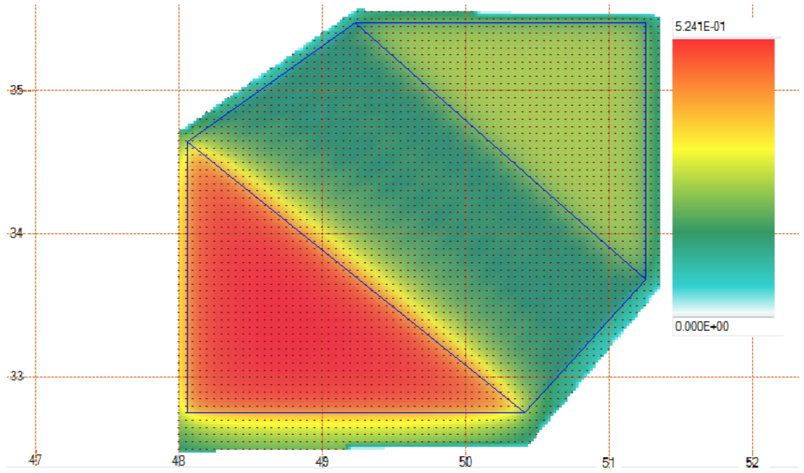

Figure 3. The expected PGA contour corresponding to the return period of 475.

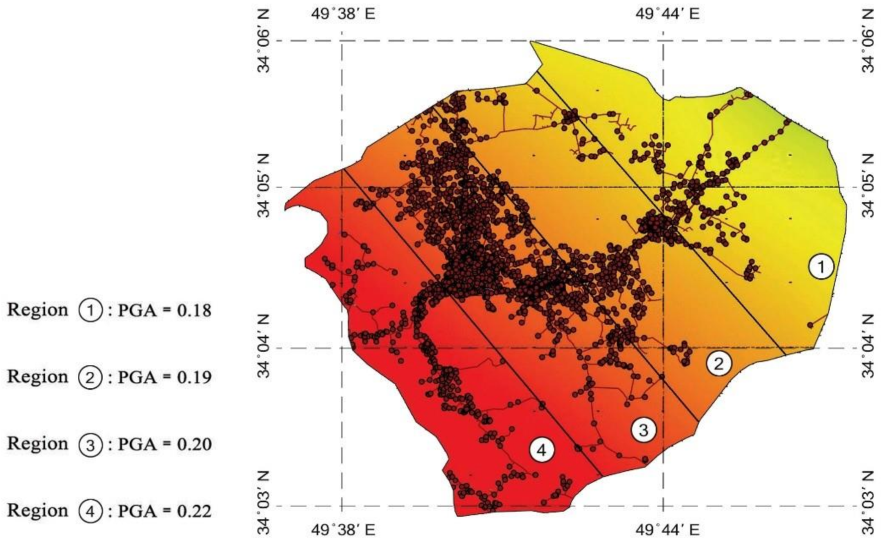

Figure 4. Seismic hazard map of the Arak electric power system

2.2. SEISMIC LOSS ESTIMATION BY UTILIZING THE HAZUS PLATFORM

The Hazus, earthquake loss estimation methodology, is a joint project of FEMA and the U.S. National Institute of Building Science and includes how to assess the damage caused by earthquakes to various systems, including vital infrastructures [17]. The technical manual of this methodology can be used to perform various analyzes. According to the Hazus technical manual, the vital infrastructures are divided into two categories: transportation systems and utility systems. The power grid is also a subset of the application systems. A power grid is divided into three sections: transmission lines, substations, and power plants. Each of these components can be vulnerable to severe earthquakes. In this study, due to the focusing on the power distribution network, the transmission lines and substations have been investigated.

2.2.1. POWER DISTRIBUTION NETWORK ELEMENTS

Power transmission lines transfer electricity from power plants to customer locations, and those are the final phase in the delivery of electric power. Distribution circuits in Arak city are divided into different parts, including poles, wires, and in-line types of equipment. Primarily distribution circuits carry the medium voltage to substations located near the premises, then substations lower the voltage, which is used by customers or household appliances. The required input to estimate the damage to distribution circuits includes the longitude and latitude location of a facility and the corresponding PGA from PSHA.An electric substation is a facility that changes or switches voltage from one level to another, provides points where safety devices such as disconnect switches can be installed, convert A.C. to D.C. and vice versa, and change frequency as needed. The required input to estimate the damage to the substations includes the longitude and latitude location of a facility and the corresponding PGA from PSHA output.

2.2.2. LOSS ASSESSMENT PROCEDURE

Hazus methodology defines different damage states that are generally divided into: Slight/Minor (the failure of 5% of the equipment for substations and 4 % of all distribution circuits), Moderate (the failure of 40% of the equipment for substations and 12% of all distribution circuits), Extensive (the failure of 70% of the equipment for substations and 50% of all distribution circuits) and Complete (the failure of all of the equipment for substations and 80% of all distribution circuits).Damage functions of different components of the power network can be calculated using the log-normal distribution, medians values, and standard deviations. In this study, because Arak power grids are of the standard components and unanchored type, the unanchored tables are used.Due to the spatial PGAs obtained for different regions in Arak city and the corresponding fragility curves, it is possible to determine the probability of damages to the distribution circuits. The mean and standard deviation (β) for each damage state were calculated using the log-normal distribution to obtain the probability of damages, concerning the PGA value of each region. The probability of damages for distribution circuits, for the 475 and 2475 years return period, are respectively presented in table 5 and 6. Also, the diagrams of results have been illustrated in figure 5 and 6.

Table 5. Damage Algorithms for Distribution Circuits (Return period 475 years)

Region	Damage State	Median (g)	β	Probability
1	slight/minor	0.24	0.25	0.34
	moderate	0.33	0.2	0.11
	extensive	0.58	0.15	0.0006
	complete	0.89	0.15	0.0000037
2	slight/minor	0.24	0.25	0.36
	moderate	0.33	0.2	0.13
	extensive	0.58	0.15	0.0009
	complete	0.89	0.15	0.0000062
3	slight/minor	0.24	0.25	0.40
	moderate	0.33	0.2	0.15
	extensive	0.58	0.15	0.0015
	complete	0.89	0.15	0.000013
4	slight/minor	0.24	0.25	0.44
	moderate	0.33	0.2	0.19
	extensive	0.58	0.15	0.0026
	complete	0.89	0.15	0.000028

Table 6. Damage Algorithms for Distribution Circuits (Return period 2475 years)

Region	Damage State	Median (g)	β	Probability
1	slight/minor	0.24	0.25	0.72
	moderate	0.33	0.2	0.51
	extensive	0.58	0.15	0.05
	complete	0.89	0.15	0.002
2	slight/minor	0.24	0.25	0.74
	moderate	0.33	0.2	0.55
	extensive	0.58	0.15	0.07
	complete	0.89	0.15	0.0035
3	slight/minor	0.24	0.25	0.78
	moderate	0.33	0.2	0.61
	extensive	0.58	0.15	0.10
	complete	0.89	0.15	0.0065
4	slight/minor	0.24	0.25	0.82
	moderate	0.33	0.2	0.67
	extensive	0.58	0.15	0.15
	complete	0.89	0.15	0.011

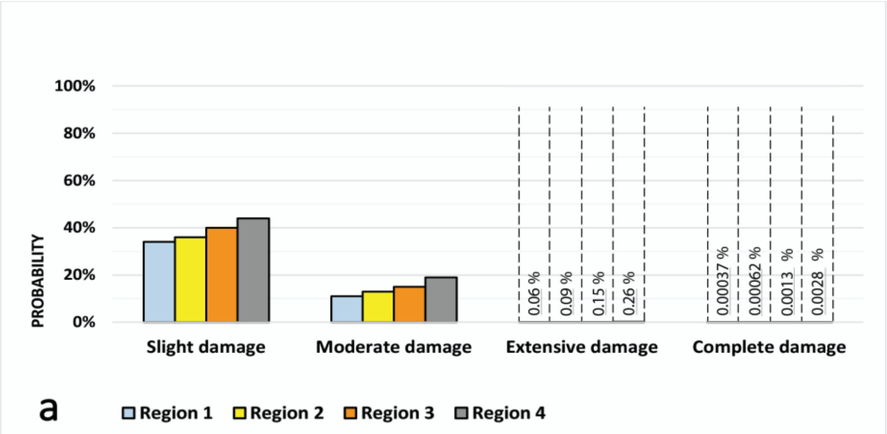

Figure 5. Distribution circuits damage algorithm diagram (Return period 475 years)

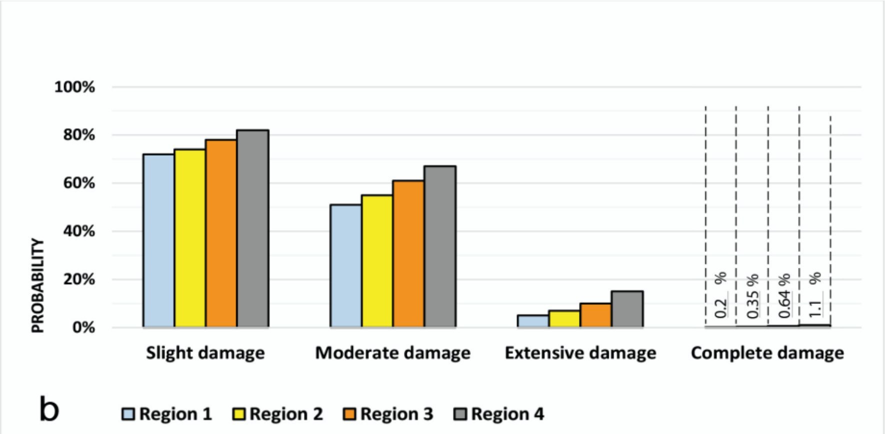

Figure 6. Distribution circuits damage algorithm diagram (Return period 2475 years)

High voltage values have been used to calculate for the damage to the substations because the substations in the Arak electricity distribution network are of high voltage type. The probability of damages for substations, for the 475 and 2475 years return period, are respectively presented in tables 7 and 8. The diagrams of results have been illustrated in figures 7 and 8.

Table 7. Damage Algorithms for Substations (Return period 475 years)

Region	Damage State	Median (g)	β	Probability
1	slight/minor	0.09	0.5	0.74
	moderate	0.13	0.4	0.65
	extensive	0.17	0.35	0.55
	complete	0.38	0.35	0.19
2	slight/minor	0.09	0.5	0.75
	moderate	0.13	0.4	0.67
	extensive	0.17	0.35	0.57
	complete	0.38	0.35	0.20
3	slight/minor	0.09	0.5	0.76
	moderate	0.13	0.4	0.69
	extensive	0.17	0.35	0.60
	complete	0.38	0.35	0.23
4	slight/minor	0.09	0.5	0.78
	moderate	0.13	0.4	0.72
	extensive	0.17	0.35	0.63
	complete	0.38	0.35	0.25

Table 8. Damage Algorithms for Substations (Return period 2475 years)

Region	Damage State	Median (g)	β	Probability
1	slight/minor	0.09	0.5	0.87
	moderate	0.13	0.4	0.84
	extensive	0.17	0.35	0.80
	complete	0.38	0.35	0.43
2	slight/minor	0.09	0.5	0.88
	moderate	0.13	0.4	0.85
	extensive	0.17	0.35	0.81
	complete	0.38	0.35	0.46
3	slight/minor	0.09	0.5	0.89
	moderate	0.13	0.4	0.87
	extensive	0.17	0.35	0.83
	complete	0.38	0.35	0.49
4	slight/minor	0.09	0.5	0.90
	moderate	0.13	0.4	0.89
	extensive	0.17	0.35	0.86
	complete	0.38	0.35	0.53

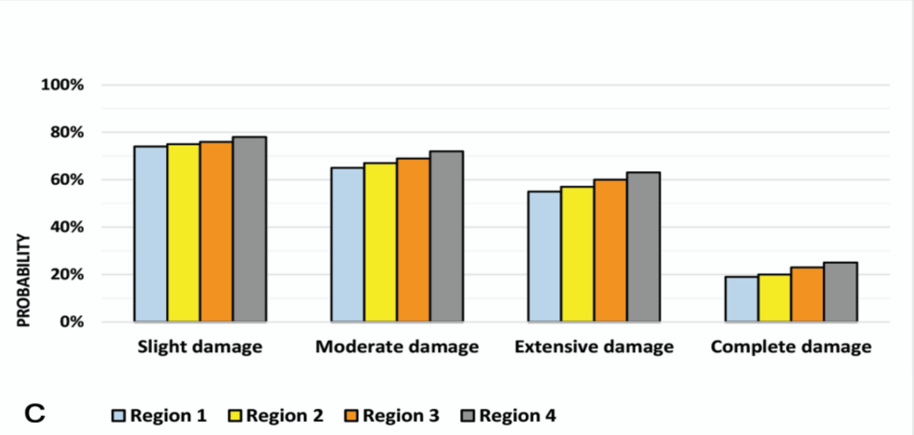

Figure 7. Substations damage algorithm diagram (Return period 475 years)

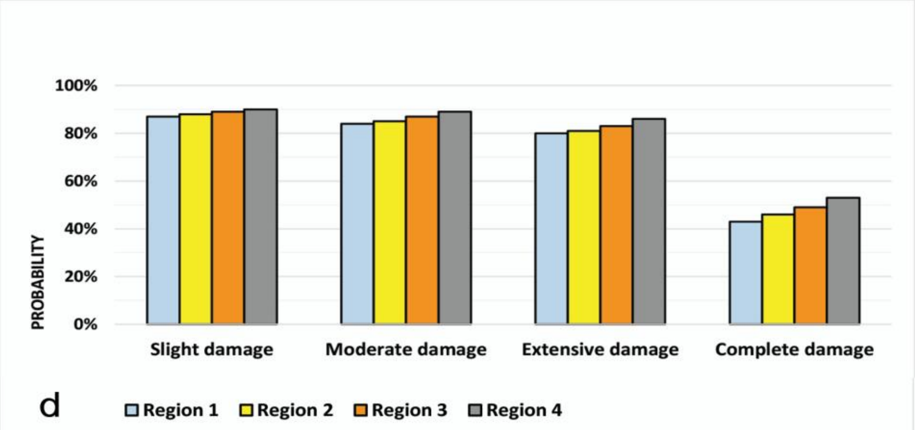

Figure 8. Substations damage algorithm diagram (Return period 2475 years)

3. RESULTS AND DISCUSSION

The calculations of financial losses are divided into direct and indirect losses. Direct losses include the cost of repairs, the cost of replacing the damaged part, the cost of capital loss, and the cost of restarting, which is directly related to the damage caused by an earthquake. Indirect losses also deal with damages that do not primarily relate to the damage suffered but are caused by the same damages. In this study, indirect losses were not investigated due to the extent and complexity. Direct financial losses for distribution networks in two parts, the distribution circuits, and the substations were investigated. The Hazus methodology has suggested guidelines for doing these analyses, but it also has mentioned that there is no need for full compliance with these studies, and changes can be made in cases where the user has sufficient expertise and information. By using the GIS information in the Arak power distribution network as well as the price breakdowns from the electricity distribution company (Table 9), and the probabilities obtained in the previous section, the amount of financial loss per kilometer of distribution circuits after an earthquake has been calculated. Finally, the amount of financial losses to the entire distribution circuits is calculated using the amount of losses per kilometer of the network and the total length of the network.

Figure 9 .Damage in Distribution Circuits(2017 Kermanshah Earthquake__Iran)

Table 9. Cost for the construction of distribution circuits in 2018 (USD)

Type of project	**Unit**	**Amount**	**Cost**
Construction of one-kilometre distribution Circuit with 70 mm aluminium wire	Kilometre	1	8,900
Construction of one-kilometre distribution Circuit with 120 mm aluminium wire	Kilometre	1	11,025

Table 10. Possible financial losses of distribution circuits with 70 mm aluminium wire(Return period 475 years)

Region	**Damage State**	**Probability**	**Best Estimate Damage Ratio**	**Possible financial losses (USD)**	**Losses per kilometer(USD)**	**Total losses (USD)**
1	slight/minor	0.34	0.05	150	304	14940
	moderate	0.11	0.15	150		
	extensive	0.0006	0.6	3		
	complete	0.0000037	1	0.03		
2	slight/minor	0.36	0.05	162	342	65368
	moderate	0.13	0.15	174		
	extensive	0.0009	0.6	4.6		
	complete	0.0000062	1	0.5		
3	slight/minor	0.40	0.05	178	397	125072
	moderate	0.15	0.15	210		
	extensive	0.0015	0.6	8.01		
	complete	0.000013	1	0.11		
4	slight/minor	0.44	0.05	197	469	35202
	moderate	0.19	0.15	257		
	extensive	0.0026	0.6	14		
	complete	0.000028	1	0.2		

Table 11. Possible financial losses of distribution circuits with 70 mm aluminum wire(Return period 2475 years)

Region	**Damage State**	**Probability**	**Best Estimate Damage Ratio**	**Possible financial losses (USD)**	**Losses per kilometer(USD)**	**Total losses (USD)**
1	slight/minor	0.72	0.05	320	1331	65227
	moderate	0.51	0.15	687		
	extensive	0.05	0.6	303		
	complete	0.002	1	20		
2	slight/minor	0.74	0.05	331	1482	283203
	moderate	0.55	0.15	737		
	extensive	0.07	0.6	384		
	complete	0.0035	1	30		
3	slight/minor	0.78	0.05	348	1791	564344
	moderate	0.61	0.15	819		
	extensive	0.10	0.6	566		
	complete	0.0065	1	56		
4	slight/minor	0.82	0.05	364	2158	161868
	moderate	0.67	0.15	894		
	extensive	0.15	0.6	801		
	complete	0.011	1	97		

Table 12. Possible financial losses of distribution circuits with 120 mm aluminum wire(Return period 475 years)

Region	**Damage State**	**Probability**	**Best Estimate Damage Ratio**	**Possible financial losses (USD)**	**Losses per kilometer(USD)**	**Total losses (USD)**
1	slight/minor	0.34	0.05	187	377	21906

	moderate	0.11	0.15	187		
	extensive	0.0006	0.6	4		
	complete	0.0000037	1	0.04		
2	slight/minor	0.36	0.05	201	424	48755
	moderate	0.13	0.15	216		
	extensive	0.0009	0.6	5		
	complete	0.0000062	1	0.7		
3	slight/minor	0.40	0.05	220	492	168707
	moderate	0.15	0.15	261		
	extensive	0.0015	0.6	10		
	complete	0.000013	1	0.14		
4	slight/minor	0.44	0.05	244	581	34886
	moderate	0.19	0.15	319		
	extensive	0.0026	0.6	17		
	complete	0.000028	1	0.3		

Table 13. Possible financial losses of distribution circuits with 120 mm aluminum wire(Return period 2475 years)

Region	**Damage State**	**Probability**	**Best Estimate Damage Ratio**	**Possible financial losses (USD)**	**Losses per kilometer(USD)**	**Total losses (USD)**
1	slight/minor	0.72	0.05	397	1649	95642
	moderate	0.51	0.15	851		
	extensive	0.05	0.6	375		
	complete	0.002	1	25		
2	slight/minor	0.74	0.05	410	1836	211227
	moderate	0.55	0.15	913		
	extensive	0.07	0.6	476		
	complete	0.0035	1	37		
3	slight/minor	0.78	0.05	432	2219	761231
	moderate	0.61	0.15	1015		
	extensive	0.10	0.6	701		
	complete	0.0065	1	70		
4	slight/minor	0.82	0.05	452	2673	160413
	moderate	0.67	0.15	1108		
	extensive	0.15	0.6	992		
	complete	0.011	1	121		

Possible financial losses to electricity substations have been assessed, such as distribution circuits using the costs received from the electricity distribution company (Table 14). The costs of total potential losses to substations have been calculated in different areas of Arak city using the amount of financial losses for each substation of the network.

Figure 10.Damage in Substations (2017 Kermanshah Earthquake__Iran)

Table 14. Cost for the construction of Substations in 2018 (USD)

Type of project	Unit	Amount	Cost
Construction of one substation (630 KVA)	Device	1	30309
Construction of one substation (315 KVA)	Device	1	8872

Table 15. Possible financial losses of substations (630 KVA) for a return period of 475 years

Region	Damage State	Probability	Best Estimate Damage Ratio	Possible financial losses (USD)	Losses for each substation (USD)	Total losses (USD)
1	slight/minor	0.74	0.05	1121	18366	0
	moderate	0.65	0.11	2193		
	extensive	0.55	0.55	9201		
	complete	0.19	1	5849		
2	slight/minor	0.75	0.05	1136	19189	441359
	moderate	0.67	0.11	2243		
	extensive	0.57	0.55	9535		
	complete	0.20	1	6273		
3	slight/minor	0.76	0.05	1160	20343	4821385
	moderate	0.69	0.11	2317		
	extensive	0.60	0.55	9985		
	complete	0.23	1	6880		
4	slight/minor	0.78	0.05	1186	21656	454790
	moderate	0.72	0.11	2393		
	extensive	0.63	0.55	10468		
	complete	0.25	1	7607		

Table 16. Possible financial losses of substations (630 KVA) for a return period of 2475 years

Region	Damage State	Probability	Best Estimate Damage Ratio	Possible financial losses (USD)	Losses for each substation (USD)	Total losses (USD)
1	slight/minor	0.87	0.05	1323	30792	0
	moderate	0.84	0.11	2827		
	extensive	0.80	0.55	13335		
	complete	0.43	1	13305		
2	slight/minor	0.88	0.05	1333	31725	729689
	moderate	0.85	0.11	2864		
	extensive	0.81	0.55	13586		
	complete	0.46	1	13942		
3	slight/minor	0.89	0.05	1353	33094	7843443
	moderate	0.87	0.11	2920		
	extensive	0.83	0.55	13969		
	complete	0.49	1	14851		
4	slight/minor	0.90	0.05	1364	34731	729352
	moderate	0.89	0.11	2967		
	extensive	0.86	0.55	14336		
	complete	0.53	1	16063		

Table 17. Possible financial losses of substations (315 KVA) for a return period of 475 years

Region	Damage State	Probability	Best Estimate Damage Ratio	Possible financial losses (USD)	Losses for each substation (USD)	Total losses (USD)
1	slight/minor	0.74	0.05	328	5376	1193528
	moderate	0.65	0.11	642		
	extensive	0.55	0.55	2693		
	complete	0.19	1	1712		
2	slight/minor	0.75	0.05	332	5617	4016247
	moderate	0.67	0.11	656		

	extensive	0.57	0.55	2791		
	complete	0.20	1	1836		
3	slight/minor	0.76	0.05	339	5955	14416779
	moderate	0.69	0.11	678		
	extensive	0.60	0.55	2923		
	complete	0.23	1	2014		
4	slight/minor	0.78	0.05	347	6339	2675188
	moderate	0.72	0.11	700		
	extensive	0.63	0.55	3064		
	complete	0.25	1	2227		

Table 18. Possible financial losses of substations (315 KVA) for a return period of 2475 years

Region	Damage State	Probability	Best Estimate Damage Ratio	Possible financial losses (USD)	Losses for each substation (USD)	Total losses (USD)
1	slight/minor	0.87	0.05	387	9013	2000959
	moderate	0.84	0.11	827		
	extensive	0.80	0.55	3903		
	complete	0.43	1	3894		
2	slight/minor	0.88	0.05	390	9286	6639974
	moderate	0.85	0.11	838		
	extensive	0.81	0.55	3976		
	complete	0.46	1	4081		
3	slight/minor	0.89	0.05	396	9687	23453257
	moderate	0.87	0.11	855		
	extensive	0.83	0.55	4089		
	complete	0.49	1	4347		
4	slight/minor	0.90	0.05	399	10166.	4290231
	moderate	0.89	0.11	868		
	extensive	0.86	0.55	4196		
	complete	0.53	1	4702		

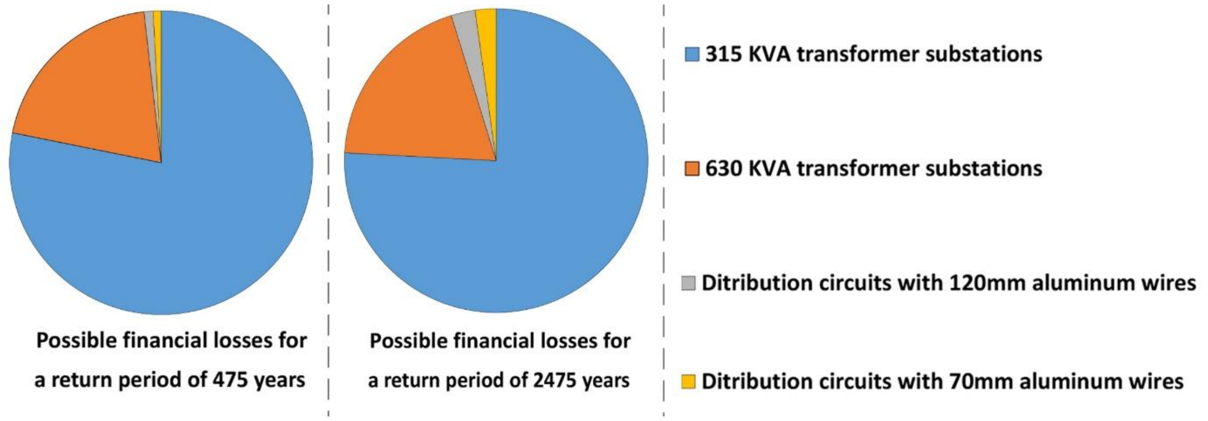

Figure 11. (left) Possible financial losses for a return period of 475 years, (right) Possible financial losses for a return period of 2475 years.

4. CONCLUSION

In this study, a comprehensive spatial seismic loss assessment at the power distribution network in Arak city in Iran has been comprehensively investigated. The results of the physical and economic damages show that when a severe earthquake occurs, irreparable damages will happen to the power distribution network. As mentioned, if there are any disruptions in the distribution network, it will cause problems for inhabitants and consequently can affect the other infrastructure systems as well. After analyzing, it was ascertained that the seismic hazard in the north-eastern part of Arak city is at the lowest level and in the south-west region is at the highest level. Given this achievement, better decisions can be made in terms of seismic risk reduction over the distribution network, and the results of this study can be used to strengthening or sustaining the network. Finally, the potential financial losses caused by earthquakes were calculated for 630 km of distribution circuits with 70 mm aluminum wire, 576 km of distribution circuits with 120 mm aluminum wire, 281 substations with 630 KVA and 3780 substations with 315 KVA separately. Due to the estimated damages, it can be seen that the financial losses to the substations are more than the distribution circuits, and for strengthening to reduce earthquake hazards, substations are of priority. In comparison with the substations themselves, the 315 KVA substations are more vulnerable than the 630 KVA substations.

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