Research Paper

Cost-benefit Analysis of Earthquake Costs and Building Retrofitting Costs in Iran

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ABSTRACT

Background: This article examines the cost of financial damages caused by earthquakes in the building sector and compares it with the estimation of retrofitting in Iran. This study compares the costs of two scenarios: "Action after the earthquake" and "strengthening the structures before the earthquake."

Materials and Methods: In this study, data obtained from governorates and building retrofitting engineering companies have been used. The scope of the study is earthquakes that occurred in the geographical area of Iran. Among them, 8 earthquakes were specifically studied: Mianeh, Ahar and Haris, Qator, Murmori, Khorasan, Damghan and Shahroud, Goharan, Hormozgan and Ezgele. Using the time value of money method to the value of 2021, we converted the estimated and realized costs to enable comparison and aggregation.

Results: The cost-benefit comparison of policies of action after the earthquake and retrofitting before the earthquake shows that Iran has suffered as much as 238 million USD in losses due to the lack of building resilience against earthquakes. The results show that the policy of retrofitting structures before an earthquake is significantly more optimal than the other scenario.

Conclusion: The comparison of the two policy scenarios examined in this study shows that retrofitting buildings before an earthquake, on the one hand, prevents vast losses, and on the other hand, increasing the number of earthquake-resistant houses reduces the amount of earthquake damage.

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Introduction

Natural disasters such as floods, earthquakes, and typhoons often have destructive effects on human settlements and result in heavy losses and damages to their residents. As a result of these disasters, buildings, and infrastructures are destroyed, and huge economic and social impacts are imposed on societies and countries. Despite the tremendous technological advances in the past centuries, humans are still helpless against unexpected natural events, such as earthquakes, floods, and so on. These calamities occasionally result in casualties and financial losses. During the 20th century, more than 1100 destructive earthquakes occurred in different parts of the world [1], 90% of which mainly led to the collapse of buildings that lacked sufficient engineering and safety principles [2]. According to a 2003 United Nations report, Iran ranks first among countries in the world regarding the number of earthquakes, with a magnitude of 5.5. Iran has one of the highest ranks in terms of vulnerability caused by earthquakes and the number of people killed. According to the same report, earthquakes are the dominant natural disaster in Iran [3]. A fundamental fact about these disasters is that not much can be done at the moment of their occurrence. However, planning can neutralize or minimize their impacts [4].

How countries react to disasters depends on each country's social resilience and infrastructural preparedness in natural disasters [5]. Therefore, interdisciplinary research, which includes various sciences from human fields to civil and physical fields, studies and examines resilience and reduces the effects of such disasters on human life as much as possible [2]. In the last two decades, these new approaches have led to a more evolved attitude towards the concept of "development." In this new look at development, referred to as "sustainable development," social and intergenerational needs are at the program's center. Sustainable development has much in common with natural disaster risk reduction on many levels. Reducing the risk of natural disasters, especially in the social dimension, is connected to sustainable development and is recognized as one of the sub-branches of sustainable development [4]. Also, the destruction of infrastructure and the environment caused by disasters imposes costs on sustainable development.

The main challenge for governments facing natural disasters as a shock is the losses they cause. Governments take measures to increase resilience to reduce the risk of direct and indirect costs caused by natural disasters [6]. According to the geographical features of Iran, earthquakes are one of the country's most frequent natural disasters. The location of Iran in the high-risk zone of earthquakes and the experience of large earthquakes on the one hand, and the existence of worn-out urban and rural structures with old and non-engineering buildings without sufficient resistance to earthquakes, on the other hand, have led to a very high statistics of life and financial losses in Iran. Therefore, deciding to increase resilience against earthquakes is one of the policy priorities regarding crisis management in the country [3]. The general crisis management policies reflect the importance and necessity of growing resilience against disasters. From the general policies of "prevention and reduction of risks caused by natural disasters and unforeseen events" announced in 2005, prevention and foresight to reduce the risks caused by natural disasters, especially earthquakes, is considered a priority for the country. Based on this reasoning, it is logical to spotlight policymaking to increase resilience against earthquakes. The prerequisite for any action in the direction of macropolitics is to conduct cost-benefit studies to determine how beneficial the intended action will be for the country from an economic-social point of view. This research aims to evaluate the cost-benefit of retrofitting buildings in selected earthquakes in Iran to prevent and reduce risks caused by natural disasters and unexpected events.

Among the studies in the world that deal with the cost-benefit analysis of pre-earthquake retrofitting and post-earthquake reconstruction, we can refer to the research of Altay et al. Following the devastation of the 1999 earthquake in Turkey, there was an urgent need to evaluate the benefits of retrofitting measures to reduce casualties. Therefore, Altay et al. performed a cost-benefit analysis to implement different seismic retrofitting measures on a typical and vulnerable apartment building in Istanbul [7]. In another study by Tian and Ren in Romania, the cost-benefit analysis for earthquake resistance and the costs of post-earthquake repairs were compared. This study was based on the usual method of retrofitting concrete buildings in Romania [8]. Regarding domestic research, no study has examined the cost-benefit of action policy after the earthquake and retrofitting policy. However, much research has been conducted on introducing optimal crisis management strategies. In this regard, Poursadeqiyan et al. examined disaster management planning and environmental hazards in the direction of sustainable development. This research shows that crises do not determine the amount of damage, but officials' response to the situation determines the amount of damage [9]. Currently, the main hypothesis is to prove the cost-effectiveness of retrofitting measures against the reconstruction costs after the earthquake. In other words, the study aims to compare the reconstruction costs caused by the earthquake with the seismic retrofitting costs of the buildings before the earthquake. The scope of the current research is the study of 8 earthquakes in Mianeh, Ahar and Haris, Qator, Murmori, Khorasan, Damghan and Shahroud, Goharan, and Ezgele in different years. The criteria for selecting these earthquakes were the magnitude of the earthquakes and the severity and amount of damage caused. However, due to the double-digit and high inflation rate in recent years in Iran, we tried to select earthquakes for the last decade so that we do not face outliers and unanalyzable data when updating the figures. Therefore, the present study aims to compare the costs of two scenarios of "action after the earthquake" and "strengthening structures before the earthquake" in the earthquakes of Mianeh, Ahar and Haris, Qator, Murmori, Khorasan, Damghan and Shahroud, Goharan, and Ezgele, which occurred in different years.

Materials and Methods

Research design

The current research is a comparative study that requires information on strengthening buildings against earthquakes and their reconstruction costs. Comparative studies generally compare statistics, identify common and opposite points, and derive desired results from the differences and commonalities of the statistics [10]. Therefore, exploring and comparing statistics and information in two or more different scenarios is the main field of comparative studies. Such information does not exist in a ready and unified form. Therefore, we need estimation methods to obtain information. One way to estimate statistical series is scenario building. The advantage of scenario planning is that it provides estimates in a minimum, maximum, and average range, and the actual statistics rarely falls outside these limits [11]. This study has also made such a method the basis of its work, explaining that the average values have been set as the basis to enable a uniform comparison.

Research tools

There are two ways to estimate the costs of reconstructing buildings damaged by past earthquakes. First, we can obtain the information by designing a questionnaire and sending it to the relevant organizations or estimating these costs without sufficient information. It means that by estimating the current construction price through construction companies and adjusting these prices by using the construction price index at the time of the earthquake, the final cost of damages was estimated according to the number of destroyed houses and the average size. However, the second way is to extract information using government reconstruction budgets in earthquake-affected areas. Although these costs may not be exact, they are more reliable because they have been realized.

On the other hand, the cost of retrofitting the building before the earthquake is abstract and has never happened. Therefore, these costs should be estimated from the beginning. For this purpose, a tabular questionnaire was designed and sent to companies specializing in building retrofitting to extract the cost per meter of retrofitting. This estimate is made using average values. The final results are obtained using these data, based on the number of damaged houses in each earthquake and adjusting the price to the year of the earthquake according to the construction price index. Finally, the estimated costs for both modes are compared, and a cost-benefit analysis is presented.

One of the main topics of financial economics is the time value of money. Inflation and interest rates change the value of cash over time. Usually, the money we have access to today is worth more than the money earned in the future. In the literature on the economic evaluation of projects, present value, and future value are the methods of calculating the real value of funds at different times. The time value of money is an essential financial concept that states that the value of money in the present is greater than the amount received in the future. This issue is inherent in the nature of money because the money you have now can be invested and earn a return, thus creating more money in the future. The time value of money is also related to inflation and purchasing power. Both factors should be considered, as well as any return generated by investing money. The time value of money is an essential concept for individuals and in finance and cost-benefit studies of projects [12].

For example, when the goal is to know how much of the value of money available today is comparable to the amount of money in the future in terms of purchasing power (real value), this comparison is possible through the formula of future value and growth rate (inflation and interest). However, this question can be asked in reverse. This means that today's funds from the past can be compared with how much money is in terms of value and purchasing power. This comparison can also be calculated using the discount rate and the present value formula.

In this report, in the first stage, the costs of retrofitting in earthquake years should be estimated. These figures are calculated using the present value formula and the discount rate. In this estimate, the inflation rate of the construction sector (construction price index at the constant price of the year 2016) is considered a proxy for the discount rate. The formula for calculating the present value of amounts is defined in the following structure (Equation 1).

1 $$PV = \frac{FV}{(1+i)^{nt}}$$

In the formula above, represents the current value, future value, discount rate, time, and finally, is the same number of courses [13].

Logical assumptions of research

An acceptable and rational hypothesis should be considered before any mathematical operation to avoid some analytical and calculation errors. Among the earthquakes mentioned in this report, due to the extent and high power of the earthquake destruction, the reconstruction costs may not have been proportionated to the destruction, and the custodian institutions may spend more money on the reconstruction of the earthquake-affected areas in the future. It should also be noted that all the costs incurred are unrelated to reconstruction, and a percentage of them belong to the costs of repairing minor damage to buildings caused by the earthquake. However, due to the impossibility of separating costs and predicting unrealized costs, the total costs incurred up to the time of compiling this article have been compared with the costs of retrofitting, which does not seem to be an unreasonable assumption.

On the other hand, to calculate and estimate the costs of retrofitting in each earthquake, we need the average size of residential houses in the earthquake-affected area. These data are calculated using the square footage and the number of destroyed houses, which is almost consistent with the housing population data in 2016. Another main assumption of this research is the possibility of retrofitting all available structures. Of course, it should be kept in mind that some residential units cannot be retrofitted due to their traditional architectural structure. However, due to the lack of information on how to separate this category of buildings, we have to accept this assumption.

Results

Currently, damage caused by natural disasters such as earthquakes, tsunamis, floods, and so on amounts to 250 and 300 billion USD per year worldwide. This is the amount that countries have to spend to cover the damages. This cost clearly shows the necessity of policymaking in this field. Expenses and damages caused by natural disasters can be divided into direct and indirect costs. Direct costs can be seen in physical structures and human factors resulting from a catastrophe leading to destruction. However, the indirect costs are the secondary effects of the primary destruction of natural disasters [14]. Direct costs include the number of people killed, damage to buildings or infrastructure, destruction of natural resources, and so on. The indirect costs of natural disasters include unemployment costs, reduced economic growth, and social costs such as depression for the loss of family members. Another division divides earthquake damages into groups that can be 'quantified' and 'measured' and

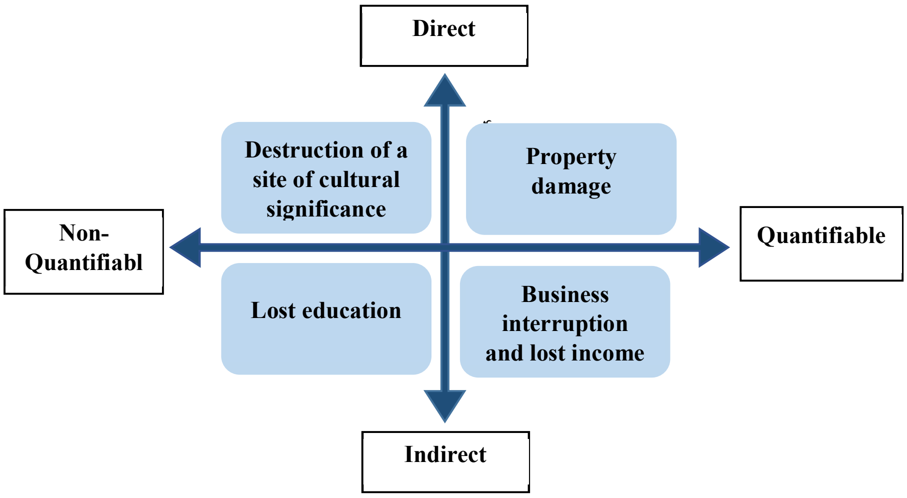

Figure 1. Dimensions of damages caused by natural disasters

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Table 1. The studied earthquakes

Earthquake - Location	The Date of the Earthquake	The Intensity of the Earthquake	The Amount of Realized Costs for the Construction and Renovation of Residential Units in the Year of Occurrence - Million USD
West Azarbaijan, Qator	February 23, 2020	9.5	23
East Azarbaijan, Mianeh	November 8, 2019	5.7	29
Ezgele	November 12, 2013	3.7	143
Fariman Khorasan Razavi	April 5, 2017	1.6	3
Murmori Ilam	August 18, 2014	2.6	11
Goharan Hormozgan	May 11, 2013	2.6	3
Ahar, Haris, Varzaghan	August 11, 2012	4.6	19
Damghan	August 27, 2010	9.5	1

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non-quantifiable and measured [14]. The Figure 1 provides an overview of these two division categories [11, 14].

The Figure 1 shows that direct and indirect effects are divided into measurable and non-measurable groups. Quantifying many of the costs involved is complex. For example, an earthquake's destruction of cultural and historical places is a direct loss, although it may be challenging to estimate. Because the replacement value cannot take cultural and historical values into account, the costs caused by psychological effects on people who suffered stress or personal loss during an earthquake cannot be calculated. Therefore, the comprehensive identification of the impact dimensions of natural disasters on human life is a very complex task. In this study, natural disaster damages only refer to the damages caused by earthquakes in the housing and building sector, which are included in the direct damages. This study analyzes the costs of building seismic retrofitting compared to the costs of action after the earthquake. The results of this analysis determine whether seismic retrofitting before an earthquake is economical or not.

Indicators' calculation

The primary purpose of this study is to examine the cost-benefit of two scenarios of retrofitting buildings before the earthquake as an active approach and the costs of action after the earthquake as a passive approach. The primary basis of the calculations of this study is the data obtained in two ways: Firstly, the data of retrofitting companies regarding the cost per square meter of building retrofitting, and secondly, the data of the governorates regarding the power of earthquake destruction, the realized costs for the reconstruction and construction of units. After calculating the number of houses and their square footage (if adopting the retrofitting policy scenario), the total cost of retrofitting is estimated, and the obtained numbers are compared with the data received from the governorates. This comparison makes it possible to calculate the damage caused by the lack of retrofitting in the year of the earthquake. Finally, the loss due to the lack of retrofitting is based on the inflation of the construction sector for the year 2021, which has been updated to allow summation and comparison of final numbers. Table 1 introduces the earthquakes studied in this research, which are the basis of the analysis. These earthquakes have been selected for study due to their destructive power and magnitude. Therefore, the expenses realized for repairing and reconstructing residential houses were received from the governorates through a letter, the data of which are reported in the Table 1.

Cost-benefit analysis of data

Table 2 compares the figures obtained from the governorates and the estimated results obtained from the research calculations. The data in this Table first estimated the loss due to the lack of retrofitting in the earthquake year, and then its value was updated for 2021. Finally, the figures were converted into USD based on the parity rate of the Rial and US Dollar (free market) in 2021. The costs that have been realized for action after the earth-

Table 2. Total loss due to lack of retrofitting

The Location of the Earthquake, Year	Total Loss Due to Lack of Retrofitting in the Year of the Earthquake (USD)	Total Loss Due to Lack of Retrofitting Based on the Value of the Year 2021 (USD)
Mianeh, 2018	1277350	2225438
Ahar and Haris, 2012	2621523	18548458
Qator, 2018	450629	7842879
Murmori, 2013	3123365	18,216,943
Khorasan, 2016	473630	2,173,957
Damghan and Shahroud, 2010	383611	5400800
Goharan Hormozgan, 2012	1391820	7151598
Ezgele, 2016	38573853	177053465
Total	-	238613538

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quake have been compared with the estimated costs for retrofitting the same number of reconstructed houses, and the results have been calculated as the loss due to the lack of retrofitting and based on the inflation of the construction sector for 2021 (as the base year for comparison). The estimation has been updated, and the dollar equivalent has been reported. As it is known, except for the Ezgele earthquake, most expenses were allocated to the Qator, Ahar, Haris, and Goharan earthquakes. Therefore, the biggest loss due to the lack of resilience in the country was from these earthquakes. Although the magnitude of the earthquake was significant and the greatest destruction and loss due to the lack of retrofitting should be expected from it, the earthquakes of Gohran, Ahar, and Haris were not very large. The intensity of their high destruction indicates the weak constructions in the earthquake-affected areas, which have incurred significant costs due to the lack of retrofitting. According to the Table 2, the loss caused by the lack of retrofitting and choosing the reconstruction scenario after the earthquake in the studied earthquakes is estimated at around 238 million USD based on the value of 2021. Although this Figure can be criticized, it is a good approximation for the lack of policies in the country's structures to prevent earthquakes. It is clear that if the basis of the conversion of rials to USD was the reference exchange rate used to pay for subsidized goods in those years (i.e. 42000 Rials), the figure was much different and larger than the figure of 238 million USD.

The Rial to Dollar exchange rate for 2021 is considered to be around 231240 Rials. Time is decisive in updating the value of losses caused by improperly retrofitting structures in earthquake-affected areas. This condition is rooted in high inflation in the country. With this explanation, the older the time of the earthquake, the higher the probability that its daily value will increase (according to the amount of expenses that occurred at the time of the earthquake). Among the earthquakes investigated in this study, based on the updated value of 2021, the Ezgele earthquake caused the greatest damage due to the lack of retrofitting. After that, the Murmori earthquake caused the country the most damage.

Information about comparing non-reinforcement losses (except for the Ezgeleh earthquake, due to the large number of costs caused by the destruction of the Ezgeleh earthquake, the report of the damage caused by it is reported numerically in Table 3) is exhibited more noticeably in Figure 2. Although it is possible to find a positive correlation between the magnitude of the earthquake and the amount of damage caused by the lack of retrofitting, more important than this is the country's significant loss for not implementing the scenario of retrofitting houses against earthquakes, which has been confirmed in all earthquakes investigated.

Table 3 is a complete report of surplus houses that could be earthquake-resistant if the retrofitting scenario was applied. This Table estimates the results of retrofitting buildings in selected earthquakes. It means how many residential units could be retrofitted with the costs incurred for reconstruction after the earthquake. These numbers were compared with the destroyed houses, and

Table 3. Comparing the construction or retrofitting of residential buildings in the two scenarios of "action after the earthquake" and "strengthening structures before the earthquake" in 2021

The Location	The Total Number of Residential Units in Case of Retrofitting	Square Meters of Residential Units in Case of Retrofitting	The Number of Destroyed Houses	Square Meters of Demolished Houses	Surplus Number of House Retrofits Due to the Pursuit of Retrofitting Policy	Surplus Square Meters of House Retrofitting Due to the Pursuit of Retrofitting Policy
Mianeh	4228	507454	3940	472800	288	482956
Ahar and Harris	26935	3232202	24498	2939760	2437	292442
Qator	5610	617130	4500	495000	1110	122130
Murmori	13244	1252429	4653	440000	8591	812429
Khorasan	2372	142331	2000	120000	372	22331
Damghan and Shahrood	2068	172351	1477	123060	591	49291
Goharan Hormozgan	4379	262754	3000	150000	2525	112755
Ezgele	221712	10011593	108735	4910000	112977	5101593
Total	281694	16198245	152803	9650620	128891	6995927

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finally, it was determined how much the damage was due to the lack of retrofitting in terms of the number of residential units. If the costs of earthquake reconstruction (action scenario after the earthquake) were spent on retrofitting costs, it was possible to retrofit significantly more than the number of destroyed houses. Based on the information in the Table 3, for example, in the Ezgele earthquake, which caused the most destruction, with

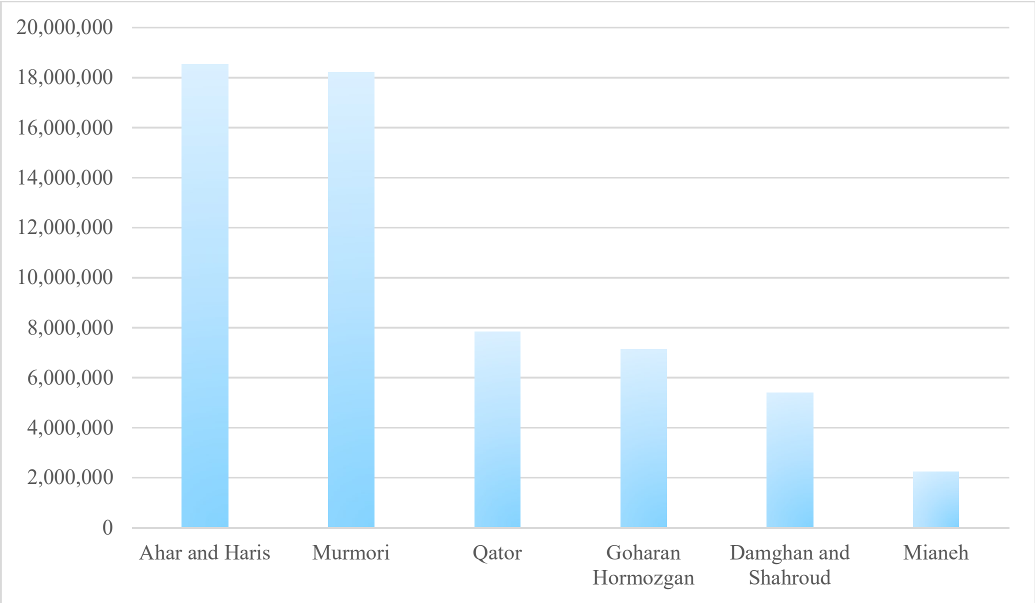

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Figure 2. The amount of loss due to lack of resilience in earthquakes based on the value of 2021 (in USD)

the costs realized after the earthquake, it was possible to retrofit 221000 houses. If this number of houses is retrofitted, it would likely reduce costs and damages for 108000 houses destroyed in the 2017 earthquake. It may also include costs such as lowering casualties and social, psychological, and economic damages. In other words, even if the life, financial, psychological, and social costs of the earthquake are to be ignored and only the costs of building destruction are the basis of the analysis, according to the assumptions of the study, the retrofitting scenario of buildings will significantly lower costs on the institutions in charge of the country compared to the action taken after the earthquake. The same scenario for the earthquakes of Ahar and Haris, Murmori, and Qator provided the possibility of retrofitting 26900, 13000, and 5000 houses, respectively, which reduced house destruction and had many positive side effects. Other cases of earthquakes will have a much better fate in retrofitting than in reconstruction after destruction, whose information is given in the Table 3.

Discussion

One important way to manage incidents caused by natural disasters is to adopt approaches based on participatory governance, especially in attracting public participation. Constructive relationships between communities and government institutions make community engagement desirable, necessary, and viable as it is likely to lead to more equitable, sustainable public decisions and improve the livability of local communities. Community engagement is important for individuals, public organizations, and governments. Community engagement is primarily part of a dialogue where organizations and communities can make decisions to create social capital. With the rise in deepening and expanding public engagement globally, the importance of community engagement has become pivotal for well-functioning. Where traditional, executive-led approaches are ineffective, community engagement is essential in its collaborative approach to service design and or delivery. For the complexity of issues like crisis management in any given community, where traditional methods have been ineffective if non-inclusive in the extreme, community engagement enables a better understanding of communities' needs and aspirations.

The basis of decision-making in crisis management should be the rationality hidden in statistics and calculations [15]. On the other hand, the cost-benefit analysis should be obtained by comparing the costs and the number of residential units of both policy scenarios under consideration [16]. Judging the choice of the most optimal method is possible when the data of each method is examined together [15, 16]. The above data and calculations show that the damage caused by the lack of retrofitting of structures before the earthquake in the 8 mentioned earthquakes is estimated to be around 238 million USD based on the dollar value. Based on the above data, if the scenario of retrofitting structures against earthquakes is given priority, it is possible to retrofit 281000 residential units with an area of 16 million m2. Another analysis is that more than 6 million m2 have been lost to the country due to the lack of retrofitting of residential structures. It can be concluded that by including the real cost estimates of retrofitting projects and the costs of direct losses, it is possible to quickly estimate the benefits of retrofitting measures in today's values.

The present research results confirm the findings of Altay et al. Their calculations showed that all retrofitting measures are highly desirable, even considering only direct losses. The sensitivity analyses performed in their calculations also showed that this conclusion is valid for a wide range of buildings, even if no casualties are associated with the collapse of the building [7]. On the other hand, the findings of this research are consistent with the results obtained in the study by Tian and Ren. The results of their research showed that despite the retrofitting scenario being more efficient in many earthquakes, the cost-effectiveness of retrofitting compared to repair costs after an earthquake depends significantly on the size of the earthquake [8].

On the other hand, the superiority of retrofitting scenarios has been indirectly mentioned in some research. For example, Nofarsti and Mousavi, in a study on the subject of estimating financial and human losses of a relatively severe earthquake in Tehran City, Iran, and its effect on the production levels and economic growth of the country, estimated the financial and human losses of a possible earthquake and its impact on economic variables.

The results indicate that if a hypothetical earthquake with a magnitude of 5.5 on the Richter scale were to occur in Tehran in 2010, we would witness the destruction of capital worth about 93 million USD and the loss of 416000 thousand people from the population of Tehran in the event of an earthquake per day (and 541000 people at night). Also, regarding the effect of the above earthquake on the level of production and economic growth rate, it should be stated that the level of gross domestic product at constant prices of 1997 after the earthquake in 2010 would have decreased to about 2.5 million USD and this could indicate a decrease of 5.5% [17].

Conclusion

The logic of cost-benefit analysis is to homogenize the available data to judge and draw conclusions among them. In this study, the results of adopting the scenario of "action after the earthquake" and the policy scenario of "strengthening structures before the earthquake" have been collected, calculated, and finally analyzed by putting them together. Of course, before making any judgments, it should be noted again that the data on the cost of strengthening structures against earthquakes in the selected earthquakes of this study is an estimate and was obtained based on contractual assumptions, so it cannot be claimed that the reported figures are very accurate. On the other hand, the purpose of this study is only the cost caused by the destruction of residential buildings, and other costs caused by the earthquake have not been investigated. However, these calculations can provide a picture of the advantages and disadvantages of adopting each of the mentioned policy scenarios for decision-makers in Iran's crisis management field.

The cost-benefit comparison of the two policies of action after the earthquake and retrofitting before the earthquake in the 8 earthquakes investigated shows that the country suffered a loss of 238 million USD due to the lack of retrofitting of buildings against earthquakes. The comparison of these two methods shows that the policy of retrofitting buildings before an earthquake, on the one hand, prevents enormous losses. On the other hand, increasing the number of earthquake-resistant houses reduces the amount of earthquake destruction. In addition to different positive effects of retrofitting, such as the reduction of mortality due to earthquake resistance of buildings and the reduction of other economic and social impacts caused by earthquakes, these are things that can prove the cost-effectiveness of the policy scenario of "strengthening structures before earthquakes" in Iran. Therefore, based on the data, calculations, and assumptions considered in this research, the policy of retrofitting structures before an earthquake is significantly more optimal than its rival scenario.

Ethical Considerations

Compliance with ethical guidelines

For this study, ethical approval was obtained from the Secretariat of the Expediency Council of the Islamic Republic of Iran, Tehran, Iran (Code: IR.SEC.REC.1401.178). Before the study, all participants from governorates and building retrofitting engineering companies were provided information about the study objectives and methods. The participants were assured of the confidentiality of their information and were free to leave the study at any time.

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Authors' contributions

Conceptualization, study design and analysis: Shahabodin Fuladi Moghaddam; Methodology and data collection: Fariborz Mohammadi; Writing the initial draft: Iman Shabanzadeh; Review and editing: Shahin Behdarvand; Supervision: Fariborz Mohammadi.

Conflict of interest

The authors declared no conflict of interest.

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References

[1] Hetu SN, Gupta S, Vu VA, Tan G. A simulation framework for crisis management: Design and use. Simulation Modeling Practice and Theory. 2018; 85(16):15-32. [DOI:10.1016/j.simpat.2018.03.001]

[2] Cai H, Lam NSN, Qiang Y, Zou L, Correll RM, Mihunov V. A Synthesis of disaster resilience measurement methods and indices. International Journal of Disaster Risk Reduction. 2018; 31(6):844-55. [DOI:10.1016/j.ijdrr.2018.07.015]

[3] United Nations Development Programme. Reducing disaster risk: A challenge for development. New York City: United Nations Development Programme; 2015. [Link]

[4] Kircher, CA, Reitherman, RK, Whitman, RV, Arnold, C. Estimation of earthquake losses to buildings. Earthquake spectra. 1997; 13(4):703-20. [DOI:10.1193/1.1585976]

[5] Tokakisa V, Polychroniou P, Boustras G. Crisis management in public administration: The three phases model for safety incidents. Safety Science. 2019; 113(28):37-43. [DOI:10.1016/j.ssci.2018.11.013]

[6] Askarizadeh M, Mohammad Nia M, Zohor, M. [Disaster and environmental risk management planning in the direction of sustainable development (Persian)]. Paper presented ar: The 4th International Congress of Geographers of the Islamic World. 14 April 2010; Zahedan, Iran. [Link]

[7] Altay G, Deodatis G, Franco G, Gülkan P, Kunreuther H. Benefit cost analysis for earthquake mitigation: Evaluating measures for apartment houses in Turkey.Paper presenred at: Second Annual IIASA-DPRI Meeting. July, 2002; Japan. [Link]

[8] TianY, Ren J, Xu Z, Qi M. A cost-benefit analysis framework for city-scale seismic retrofitting scheme of buildings. Buildings. 2018; 13(2): 477. [DOI:10.3390/buildings13020477]

[9] Poursadeqiyan M, Feyz Aref M. Preventive approach and preparation for crisis management before the outbreak. Health in Emergencies & Disasters Quarterly. 2020; 5(4):165-8. [DOI:10.32598/hdq.5.4.189.18]

[10] Kamali Y, Mirzaei J. [Comparative study of disaster management structure in Iran, Japan, India and Turkey (Persian)] Journal of Strategic Studies of Public Policy. 2017; 7(25):245-89. [Link]

[11] Kahandawa KARVD, Domingo, ND, Park, KS, Uma, SR Earthquake damage estimation systems: Literature review. Procedia Engineering. 2018; 212: 622-8. [DOI:10.1016/j.proeng.2018.01.080]

[12] Oskou Nejad M. [Economics of engineering; economical evaluating of industrial project (Persian)]. Tehran: Sharif University Press, 2011. [Link]

[13] Majidian D. [Evaluation of Industrial Plans; Technical Economic Financial Studies (Persian)]. Tehran: Industrial Management Organization Press, 2014. [Link]

[14] Carrera L, Standardi G, Bosello F, Mysiak J. Assessing direct and indirect economic impacts of a flood event through the integration of spatial and computable general equilibrium modeling. Environmental Modeling & Software. 2015; 63: 109-22. [DOI:10.1016/j.envsoft.2014.09.016]

[15] Laurien F, Martin JG, Mehryar S. Climate and Disaster Resilience Measurement: Persistent gaps in multiple hazards, methods, and practicability. Climate Risk Management. 2022; 37:100443. [DOI:10.1016/j.crm.2022.100443]

[16] Cardone D, Flora A, Manganelli B. Cost-benefit analysis of different retrofit strategies following a displacement-based loss assessment approach: A case study. Paper presented at: Tenth US National Conference on Earthquake Engineering Frontiers of Earthquake Engineering. 21-25 July 2014; Anchorage, Alaska. [Link]

[17] Nofarsti M, Mousavi R. [Financial and human capitals of a relatively severe earthquake in Tehran and its effect on the level of production and economic growth (Persian)]. Journal of Economics and Modeling. 2010; 1(3):67-84. [Link]