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Earthquake insurance in Iran: Solvency of local insurers in light of the current market practice

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Abstract:

Due to its location in one of the most seismically active regions in the world, Iran has witnessed many devastating earthquakes through history. To finance a part of these losses and reconstruction expenses, earthquake insurance has been offered as a rider of fire policy by the Iranian insurers. This mechanism, if well operated, can substantially contribute to disaster risk management. On the other hand, if the pricing and management of catastrophe risk lack a sound, risk-based practice, it might add to the problems and act to the detriment of disaster risk management. In this paper, we first compare the current earthquake insurance pricing and risk management in the Iranian insurance industry with a state-of-the-art insurance regulation in the European Union (Solvency-II). Then, we examine the consequence of following each approach in terms of business profitability and viability by conducting a numerical analysis on a hypothetical portfolio of property risks in Iran. The results suggest that maintaining the current insurance pricing and risk management techniques in Iran will probably lead to a substantial accumulation of earthquake risk for domestic firms and eventually endanger the solvency of these companies in the event of large-scale earthquake losses in future.

Keywords: Iran earthquake risk, Probabilistic catastrophe model, Insurance pricing, Insurance regulatory, Solvency

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1 Introduction

Being located in one of the most seismically active regions in the world, Iran has witnessed many devastating earthquakes through history, such as the 1978 M7.4 Tabas (USD 11 mn), the 1990 M7.4 Manjil–Rudbar (USD 2.8 bn), the 2003 M6.6 Bam (USD 1.5 bn), and most recently the 2016 M7.3 Sar-e Pol-e Zahab (USD 5 bn) [(Ibrion, Mokhtari, & Nadim, 2015) and (Maghsoudi & Moshtari, 2020)]. Although almost all these events occurred in rural areas or small-size cities with less than 100 thousand of inhabitants, the resulting socio-economic consequences have been substantial. If a similar magnitude earthquake struck a major Iranian city with millions of populations, the volume of physical and human losses would be much higher.

To compensate a part of earthquake losses and facilitate the process of reconstructions, Iranian insurance firms offer earthquake insurance as a rider of fire policy. However, despite the common practice in the global insurance market, almost none of the domestic insurers use catastrophe risk models to quantify seismic risk for pricing policies, purchasing reinsurance, and managing accumulated risks. Instead, old-fashion and seemingly underestimating pricing tables are still utilised nationally to determine earthquake insurance policies based on main construction materials and geographical location of insured buildings. This pricing approach is likely to result in insurance companies collecting insufficient premiums to cover future catastrophe losses. In a similar way, on the regulatory side, the solvency capital for catastrophe properties is not risk-based and is determined according to the amount of premium collected (which seem to be not commensurate to risk) and history of company's losses (which does not reflect long-return period events risks like earthquakes). To date, due to the low penetration rate of insurance in Iran, about 1.8% in 2022, catastrophe risks assumed by Iranian insurance companies are not significant, implying that even in the event of medium to large natural catastrophes, the insurance losses usually are reimbursable by the insurers. With the expected Iran Building Catastrophe Insurance Pool (IBCIP) starting to operate in 2023, all residential buildings will be covered under a national policy. As such, there will be likely considerable business opportunities for domestic insurers to extend their catastrophe property portfolio to provide supplementary coverage to the primary protection which IBCIP offers. These new business opportunities, although financially attractive, can dramatically expose Iranian insurance and reinsurance companies to natural hazards risk. In other words, in the event of major catastrophe events, such as earthquakes in urban cities or widespread flooding, which are likely in the Iranian geography, many local insurers can quickly become insolvent. These said, it is essential to examine the of sufficiency of the current insurance rates and the effectiveness of the solvency capital requirements mandated by Central Insurance of Iran (CII) to cover future catastrophe losses to happen in Iran.

In so doing, two parallel approaches have been followed. First, a probabilistic earthquake risk model was developed which help calculate risk-based pricing framework for earthquake insurance policies. The model entails components of a standard catastrophe risk model, namely exposure, hazard, and vulnerability which are separately adopted, tailored, or developed based on the state-of-the-art methodologies and up-to-date data. These components are convolved using GEM's OpenQuake as a probabilistic risk assessment platform to generate risk output such as Average Annual Loss (AAL) and loss Exceedance Probability (EP). In addition, a similar risk-based methodology to what employed by the European insurance solvency regime, Solvency II, was adopted to create a standard formula for determining solvency capital for given earthquake risk portfolios. A hypothetical portfolio of earthquake risks was assumed to compare the factor-based solvency capital (as mandated by CII) with a risk-based one (as determined following Solvency II methodology) to examine the sufficiency of the current earthquake rates and solvency capital. Further, the profitability of the underwriting and the likelihood of solvency is benchmarked using the values generated using the risk-based pricing method and the standard formula of solvency capital.

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This paper comprises five sections. First, a background on insurance solvency with a focus on the European Solvency-II and its proposed method for calculating risk-based solvency capital earthquake is provided in Section 2. Then, Section 3 briefly describes the evolution of earthquake risk models in Iran. Section 3 provides information on the methodology adopted to calculate risk parameters such as AAL and EP (99.5% percentile) and estimate risk-based solvency capital for a portfolio of risks with earthquake coverage. Numerical results of the proposed methodology are outlined in Section 4, where the solvency capital of a hypothetical portfolio of risks under earthquake policy is calculated using the current factor-based and the proposed risk-based methods. A discussion on the differences between the two methods and possible consequences on the viability of Iranian insurers is given in Section 5. And finally, section six concludes the process and its findings. A reference list is also provided at the end of the article.

2 Natural Catastrophe Insurance Regulations in the European Union (EU) and Iran

The significance of natural catastrophes and their impact on the viability of insurance firms has received increasing attention over time, and the occurrence of major catastrophic events such as Hurricane Andrew (1992), the Northridge Earthquake (1994), Hurricane Katrina (2005), the 2011 Great East Japan Earthquake and Tsunami has highlighted the issue. Catastrophe losses engender the solvency of small and medium reinsurance firms and consume the accumulated provisions of well-capitalised reinsurers (Anderson, 2002). While, to many, the term catastrophe is closely associated with natural hazards (e.g. earthquake, flood and windstorm), it can also be used to address intensive damages from human-made events (Lawson, Card, & Vass, 2001). Catastrophe risks have different characteristics compared to non-catastrophe losses. They are highly dependent and occur so rarely that historical claim data could not be efficiently utilised to predict future losses. As a result, the insurance industry has evolved to prepare for the consequences imposed by disasters by developing risk management rules and regulations. This section provides a brief history of the regulations regarding the insurance solvency capital as a risk management measure in the insurance industry, focusing on the European Solvency-II regime and the solvency regulations set by the Central Insurance of Iran (CII) as the national insurance regulator. In addition, technical aspects of calculating SCR in the two abovementioned regulatory systems are described with brevity.

2.1 European Insurance Solvency Regulation

In 2004, Thorburn has provided a history of the difficult times that catastrophic losses created for the insurance industry and the countries' response to these challenges in the form of developing insurance regulatory institutions and adopting solvency mandates as an effective measure to manage catastrophe risks to which insurers are exposed (Thorburn, 2004).

In general, insurance supervision aims to protect policyholders' interests by ensuring a sound financial operation and proper management in the insurance business. Therefore, effective regulations must be established to evaluate insurers' liabilities adequately and determine provisions to cover these commitments. It is also necessary to consider an extra layer of protection in the form of capital margin to respond to unexpected financial shocks, e.g. catastrophic losses. That is why solvency supervision regulations were established and improved over time.

Catastrophic losses, both natural and man-made, have resulted in higher claims provisions, reduced capital power, reduced profitability, and in some cases, made insurance firms insolvent. Remarkable examples of such bankruptcies are the 1906 San Francisco earthquake with 12 insurance companies declared insolvent, the 1992 Hurricane Andrew with nine firms being bankrupt, and the 2011 Christchurch quakes that resulted in the ruin of two insurance companies (Kelly & Stodolak, 2013).

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The first steps in harmonising Europe-wide insurance supervision were taken by the approval of the first non-life and life insurance Directives in the 1970s [(First Council Directive, 1973), (First Council Directive, 1979)]. These directives required the European Member States to comply with harmonised solvency capital requirements. The Directives were later revised by adding second and third amendments in 1982 and 1992 [(Second Council Directive, 1988), (Council Directive, 1990), (Directive, 1992), (Council Directive, 1992)] The entirety of these regulations, which were later named Solvency-0 by (Sandström, 2019), underwent a comparative examination in the 1990s, showing that they were not sufficiently taking into account the full spectrum of risks that insurance companies were exposed to. As such, new directives (known as Solvency I) were again introduced to both life and non-life insurance in 2002 to fortify the stance of insurers in the event of catastrophic losses ((Directive, 2002), (Directive, 2002)). Both Solvency-0 and Solvency-I regulations followed a similar approach in determining the Solvency Capital Margin, which was mainly based on factoring gross earned premium and gross incurred claims (Sandström, 2019). However, this was only a transitional remedy to incorporate a risk-based approach in the insurance solvency capital requirement regulations, as Solvency I was still inefficient in terms of asset and liability valuation and capital allocation (Rae, et al., 2018). A drastic reform to solvency regulation was introduced about one decade later as the Solvency-II Framework.

Influenced by the then-new risk-based banking regulation, Basel-II (Basel Committee on Banking Supervision, 2004), Solvency-II, the latest European insurance supervising regime, replaced Solvency-I in 2016. This new regime provides a more comprehensive risk-based approach for determining solvency requirements for insurance undertakings. The new regulation also includes a market-based valuation system for assessing companies' assets and liabilities (Directive, 2009). With a higher degree of confidence, this could potentially reduce the risk of insurance firms being insolvent. In addition, the Directives contribute to the harmonisation of insurance supervision in the European market. Solvency-II encompasses three pillars, the first of which, Pillar I, sets out rules for calculating risk-based technical provisions. Two types of capital requirements are represented in Pillar I: the Minimum Capital Requirement (MCR), which is the least authorised capital of insurance companies, and the Solvency Capital Requirement (SCR) which enables an insurance institution to absorb significant financial shocks, giving reasonable assurance to policyholders and beneficiaries. Under the underwriting risk category, the institution can use either a Standard Formula or an Internal Model, each having its pros and cons regarding the level of sophistication and SCR size. Despite all the promising features and improvements of Solvency-II, it has been subject to much research since its introduction [(Rae, et al., 2018), (Linder & Ronkainen, 2004), (Kousky & Cooke, 2012), (Gurenko & Itigin, 2013), (Clarke, Mitchell, & Phelan, 2014), (Baione, De Angelis, & Granito, 2018), (Deligiannakis, Zimbidis, & Papanikolaou, 2021)]. These researches mainly focused on the areas such as economic justification of the then-new solvency regime, different results obtained using the Standard Formula of Solvency-II and Internal Models, comparison between the implications of Solvency II and Solvency I, and possible improvements to the new directive.

2.2 Iranian Insurance Solvency Regulation

The Central Insurance of Iran (CII) is the regulator of the Iranian insurance market. As one of its principal duties, CII approves and enacts decrees and directives through the High Council of Insurance (HCI) to regulate different aspects of the insurance business in Iran (High Council of Insurance, 2019). Before the approval of the first Directive on the solvency capital adequacy, CII supervised the operation of Iranian insurance firms by examining monthly reports on companies' collected premiums and paid claims (Hashemi, Safari, & Kamali-Dolatabadi, 2010). As the pricing system in the Iranian insurance market was no longer tariff-based then, new regulations needed to be developed and implemented by CII to monitor the financial solvency of insurance firms. Consequently, Directive 69 was approved and enacted by HCI in 2011, which required insurance firms to put aside a factor-based solvency capital for four

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categories of risks: insurance, market, credit, and liquidity. The Directive also recognized the market value (compared to book value) as the correct method of valuing own funds in the accounting system. This regulation, which is still in place, represents five classes of solvency. A company belongs to the first solvency capital level when it keeps a solvency capital equal to or greater than the Solvency Capital Margin (SCM). Should an insurance company fail to maintain a sufficient solvency margin, it enters levels 2 to 5 depending on the capital deficit. At level 5 of solvency, CII can officially cancel the business permission of the insolvent firm. For natural catastrophe policies (fire, engineering, motor, and life), the SCM is the greatest of gross earned premium and gross incurred claims, each multiplied by a fixed risk factor (Similar to Solvency-0). These fixed factors were calculated based on an assessment carried out on the financial statements of Iranian insurance firms and the financial time series of the Iranian real estate and stock market. The computed solvency capitals of the named risks are ultimately combined assuming zero correlation between risks to form the company's SCM. Directive No. 69 was reviewed by Shahriar et al., and a number of improvements regarding changing the risk metric to VaR, using a 99% confidence level for calculation SCM, and consideration of linear correlation for different risks was suggested (Shahriar, et al., 2016).

3 Methodology and Data

This section describes the theoretical framework of the quantitative comparison between the methods for calculating earthquake risk solvency in the Solvency-II Directive and Directive 69 of the Iranian insurance regulation. In so doing, mathematical formulations are detailed in both methodologies, encompassing the selection of risk metrics, risk factors, and implementation of the risk diversification effect. Then, as a pre-requisite for calculating the solvency capital, components of a stochastic earthquake risk model for Iran are outlined, covering seismic hazard, vulnerability, exposure, and financial calculation modules. The introduced earthquake risk model estimates the 99.5 loss percentile and Average Annual Loss (AAL) of earthquakes in Iran as input to Solvency-II formulas. To feed Directive 69, the conventional earthquake risk pricing table of the industry is utilised.

A portfolio of 1500 residential dwellings across five provincial capital cities of Tehran, Esfahan, Tabriz, Ahvaz and Kerman has been considered to compare the earthquake risk solvency charge calculated by each methodology. The reason for selecting these capital cities is that they are located in various and seismicity zones and contain different composition of construction types. This allows us to consider the effect of diversification in the comparison process.

3.1 Calculation of earthquake solvency capital

3.1.1 Directive 69

High Council of Insurance (2011) requires insurance and reinsurance institutions to hold eligible own funds as the solvency capital using the fixed factors determined for different types of risks, namely underwriting, market, credit and liquidity risks. The Directive provides risk factors for miscellaneous lines of business, including catastrophe fire insurance (non-life) without any distinction between various natural catastrophes in terms of fixed risk factors and assumes zero correlation between risks in different lines of business and geographies (meaning that losses are deemed fully independent). According to this directive, to calculate the solvency charge of a property catastrophe portfolio, first, the products of gross earned premiums and gross incurred claims with their corresponding risk factors (0.580 and 0.841, respectively) are computed, and then the greatest of these values is considered as the solvency capital. Since no reliable information on the gross incurred earthquake loss claims were available to us at the time of writing this paper, we only use the term determined by gross earned premiums. In so doing, average values of earthquake premium rates of five Iranian insurance firms, which were extracted from a popular Iranian insurance quotes aggregator website[3] are employed to calculate the premium-based part of the formula for the portfolio. These rates are still based on a study conducted in 1991 by Ghafory-Ashtiany (1991) who determined the relative riskiness of different construction types in various seismic zones in Iran (please see the original table at Table A1). Table 1 presents averaged earthquake insurance premiums for masonry, concrete and steel buildings of 10 years of age in five provincial capital cities of different tectonic natures and seismic hazard levels. Needless to say, the portfolio of risks used for the comparative analysis is consistent with construction characteristics assumed in the earthquake premium table.

Table 1: Earthquake premium rates (in 1000) for different types in various province capital cities in Iran

Province	County	City	Construction type		
			Masonry	Steel	Concrete
Tehran	Tehran	Tehran	1.1	0.50	0.50
East Azarbayjan	Tabriz	Tabriz	1.1	0.50	0.49
Esfahan	Esfahan	Esfahan	0.78	0.33	0.32
Kerman	Kerman	Kerman	1.1	0.37	0.36
Khuzestan	Ahvaz	Ahvaz	0.78	0.33	0.32

3.1.2 Solvency-II

As outlined in Annex IV of Directive 2009/138/EC (2009) and CEIOPS (2010) on the application of the natural catastrophe Standardised Scenarios (standard formula), to calculate earthquake charge, the Weighted Total Value Insured (WTIV) should be computed at CRESTA level using the Total Insured Value (TIV) for each line of business. Eq.1 presents the mathematical formulation of this stage [(Directive, 2009), (Committee of European Insurance and Occupational Pensions Supervisors (CEIOPS), 2010)].

$$WTIV_{ZONE} = F_{ZONE} \times TIV_{ZONE} \qquad \text{Equation 1}$$

Since the 99.5% Value at Risk (VaR), as the risk factor, are provided at the country level in CEIOPS (2010), a relativity factor (F_{ZONE}) takes the role of adjusting the national risk factor at subnational (CRESTA) level in the Standardised Scenario. The catastrophe capital charge ($CAT_{peril-ctry}$) is then calculated by applying the effect of geographical aggregation of WTIVs of different CRESTA zone within the country of interest multiplied by Q_{CTRY} (1-in-200-year risk factor of earthquake at country level). Eq.2 illustrates the calculation of solvency capital required for earthquake risk at the country level.

$$CAT_{PERIL-ZONE} = Q_{CTRY} \times \sqrt{[WTIV_{ZONE}]^T [AggMat][WTIV_{ZONE}]} \qquad \text{Equation 2}$$

Where $[WTIV_{ZONE}]$ is the array presentation of WTIV within the country (of interest and $[WTIV_{ZONE}]^T$ is its transposed form. $[AggMat]$) is basically a correlation matrix determining how different CRESTA zones are correlated to each other in terms of experiencing simultaneous earthquake loss and it comprises elements of 1 (fully correlated), 0.5 (semi correlated), 0.25 (slightly correlated), and 0 (no correlation). CEIOPS (2010) provides sub-country correlation matrices for EEA countries in an excel spreadsheet.

[3] Azki.com

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To follow the procedure proposed by Solvency II to calculate the catastrophe charge for earthquake risks in Iran, we use the output of a stochastic earthquake risk model developed in this study, separately presented in section 3.2. This catastrophe model can produce risk results (e.g. AAL or 1-in-200-year loss) at finer administrative levels than CRESTA. In accordance with local underwriting and risk management practice in Iran, we use the county-level resolution to calculate the solvency capital. Therefore, there is no need to use a relativity factor for TIV at the county level since we already have the Q factor for each county. That said, we can rewrite Eq.1 to Eq.3:

$$CAT_{EQ-County} = Q_{County} \times TIV_{County} \quad \text{Equation 3}$$

Here, we can directly calculate each county's catastrophe charge for earthquake risk. Following that, we aggregate these charges at a province and then national level to determine the total solvency capital for a given portfolio of earthquake risks. Eq.4 and Eq.5 exhibit the mathematical form of these calculations.

$$CAT_{PERIL-ZONE} = \sqrt{[WTIV_{ZONE}]^T[AggMat_{Province}][WTIV_{ZONE}]} \quad \text{Equation 4}$$

$$CAT_{PERIL-ZONE} = \sqrt{[WTIV_{ZONE}]^T\left[AggMat_{County}\right][WTIV_{ZONE}]} \quad \text{Equation 5}$$

The symmetric aggregation matrices for province and country levels are constructed using either 1 (fully correlated), 0.5 (semi-correlated), 0.25 (slightly correlated) and 0 (non-correlated) members. It is assumed, mainly considering distance factor, that each county is fully correlated with itself and semi correlated with its neighbouring counties. In the case of provinces, due to the larger size, the neighbouring provinces are assumed to be slightly correlated.

3.2 Modelling the Earthquake Risk in Iran

As a requisite for using a risk-based methodology in calculating the earthquake risk capital charge, for example, the described method by Solvency-II, it is necessary to have a stochastic catastrophe model for quantifying the required percentile of confidence of seismic losses (here, 99.5%) at different locations and various construction types. This subsection explains how we developed an earthquake risk model for Iran utilising the most reliable methodologies and the highest quality of data. The subsection describes the risk model components: the calculation platform (OpenQuake), seismic hazard model, residential building exposure model, and vulnerability functions. Because this paper's main objective is to compare solvency capital calculation methods, efforts were made to keep the risk model development description as brief as possible.

The common practice for quantifying natural catastrophe risks in the insurance industry is (event-based) stochastic catastrophe modelling. The process incorporates three main components of hazard, exposure and vulnerability using a Monte Carlo simulation method to generate event loss tables (ELT). ELTs are used to calculate risk parameters such as Average Annual Loss (AAL) and loss Exceedance Probability (EP) curves which are employed for various underwriting and risk management decisions in the business. The practice of modelling seismic risk in Iran is rather in its early stage and a few studies have been conducted on catastrophe modelling over the last decade, e.g. (Ghafory-Ashtiany & Nasserasadi, 2012), (Pakdel-Lahiji, Hochrainer-Stigler, Ghafory-Ashtiany, & Sadeghi, 2019), (Motamed, Calderon, Silva, & Costa, 2019), (Shahbazi, Mansouri, Ghafory-Ashtiany, & Käser, 2020), and (Bastami, Abbasnejadfard, Motamed, Ansari, & Garakhaninezhad, 2022). In this study, the open-source OpenQuake platform developed by the Global Earthquake Model (GEM) foundation was utilised to do the seismic risk modelling job, due

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to its recognition in the insurance market and its flexibility in terms of input data and generation of required risk parameters.

3.2.1 Seismic hazard model

After reviewing several available studies on the seismic hazard of Iran [(Motamed, Calderon, Silva, & Costa, 2019), (Mirzaei, Gao, Chen, & Wang, 1997), (Tavakoli & Ghafory-Ashtiany, 1999), (Yazdani & Kowsari, 2013), (Şeşetyan, et al., 2018), (Khodaverdian, Zafarani, & Rahimian, 2016), (Pagani, Garcia-Pelaez, Gee, & al., 2020)), the Earthquake Model of Middle East (Şeşetyan, et al., 2018) was selected due to the availability of its OpenQuake-ready input data and credibility of the study in the earthquake engineering society. The seismic model comprises two models for line and area sources in Iran, a set of Ground Motion Prediction Model Equations (GMPE) for different seismic source characteristics in Iran (including active shallow crustal, stable shallow crustal, subduction, and deep seismicity sources), and two logic threes for treating epistemic seismic hazard uncertainty, and a soil model based on methodology suggested by Allen and Wald for taking into account amplification effect of soil (Allen & Wald, 2009). Figure 1 illustrates the Peak Ground Acceleration (PGA) distribution with an equivalent return period of 475 years in Iran, using the EMME seismic hazard model.

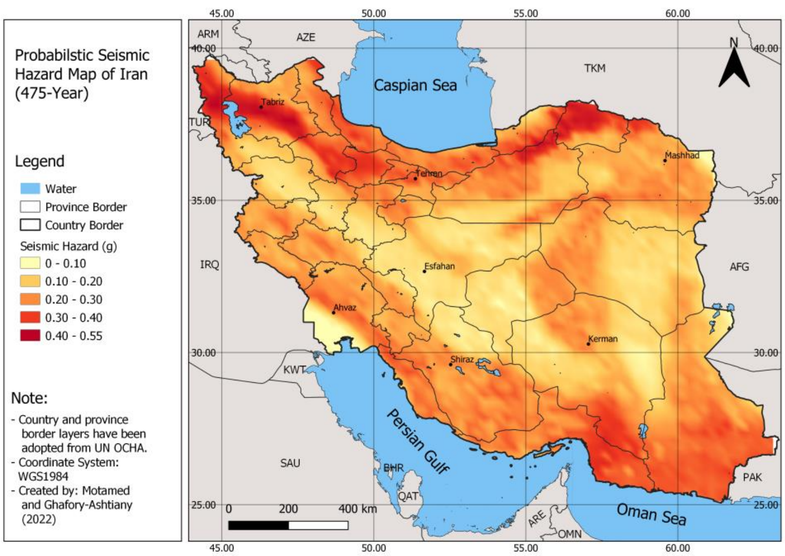

Figure 1: Spatial distribution of hazard parameter (PGA) of 475-year return period

As seen inFigure 1, the northern part of the country (Alborz and Koppe-Dagh seismotectonic zones), including the cities of Tabriz and Tehran, and south-eastern regions (central Iran and Makran zones) containing the city of Kerman show the highest levels of seismic hazard. On the flip side, the cities of Esfahan in central Iran and Ahvaz in south-western Iran belong to zones with the lowest PGA levels.

3.2.2 Residential building exposure model

The basis for building a residential building exposure model for Iran is the census data collected in the two census years of 2011 and 2016. Because of the COVID-19 pandemic, the 2021 census survey faced delay and was not ready at the time of the study. Based on the best practice of catastrophe modelling, an ideal exposure model should

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contain fields relating to the location, replacement cost, and construction characteristics such as type of material, number of storeys, and vintage of construction. Iran's 2011 building and population census collected information on the location (at the county-level data which is publicly available), construction year, and materials types. No information on the height of structures or number of storeys is gathered in five-year censuses, so, we assumed low (1-2 storeys) height for adobe and masonry, and medium height (3-6 storeys) for steel and RC buildings. This decision is in accordance with the assumptions made by Mansouri, Kiani and Amini-Hosseini, whose vulnerability curves were used in this study (Mansouri, Kiani, & Amini-Hosseini, 2014).

Another challenge was that in 2016 census the housing census stopped collecting data on the year of residential building construction. To overcome this problem, the construction time field of 2011 census data were upgraded by considering a set of expert-based assumptions. For instance, we assumed that the number dwellings increased in each county after the census 2011 were constructed with modern material such as steel and RC and according to the most recent Iranian seismic code (Standard 2800 version 4). We divided the age of buildings into three classes of pre-1985, between 1986 and 2005, and post-2006 which were approximately consistent with the data of national census and dates where different version of the Standard 2800 came into force. The building vintage was used as a proxy for the quality of construction.

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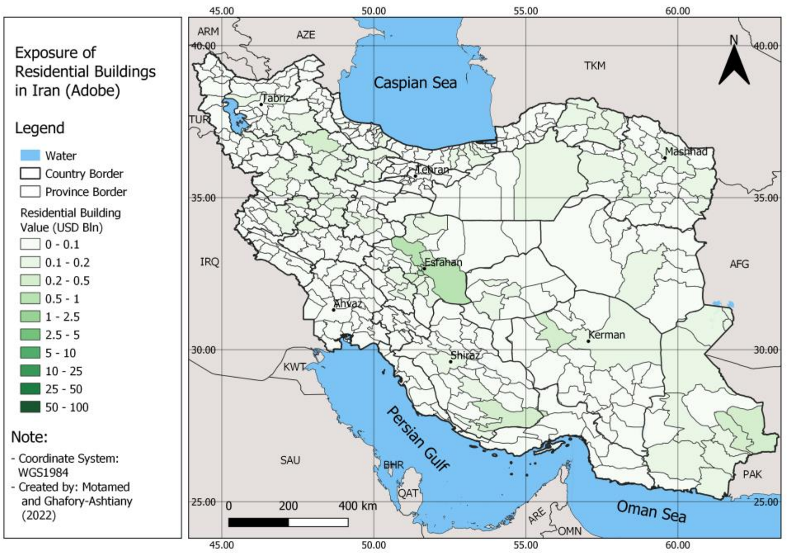
Figure 2: Examples of different construction classes in District 2 of Tehran: adobe (upper left), steel (upper right), reinforced concrete (lower left), masonry (lower right)

Photos by Ms. Niloofar Kazemi Asl

We used an auxiliary population dataset with a 30-arc-second resolution to disaggregate the county-level building exposure data to gain a finer resolution for the loss calculation purpose. Figure 3 presents the spatial distribution and value of different types of residential buildings in Iran at the county level.



(a)

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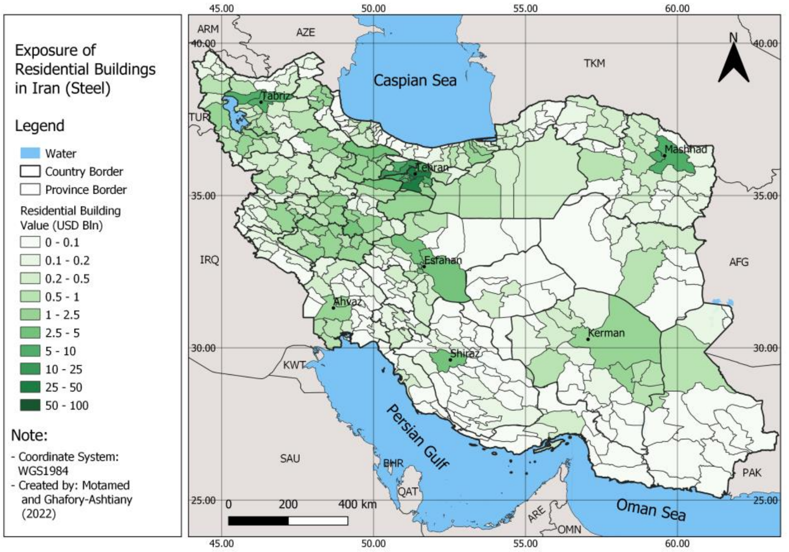

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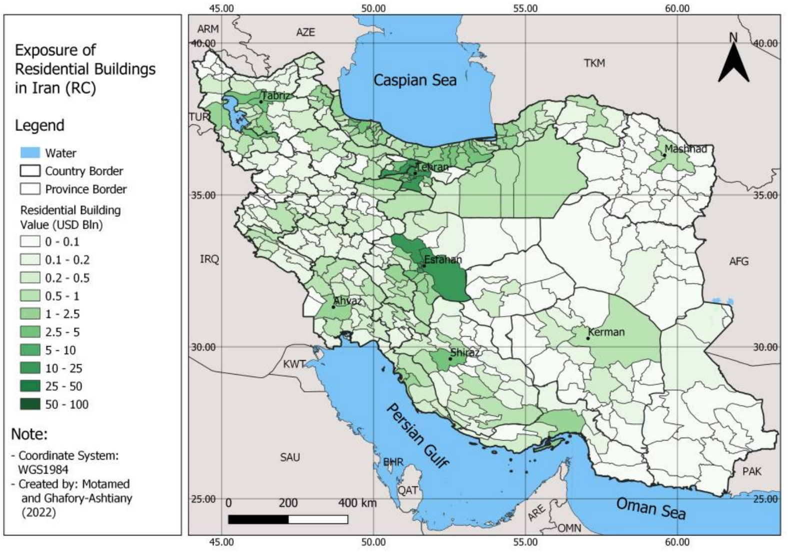

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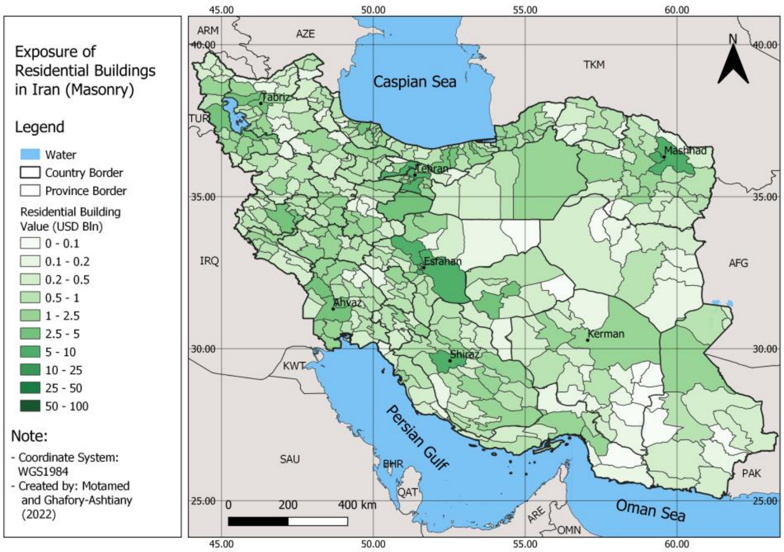

(d)

Figure 3: Exposure of residential buildings in Iran, adobe (a), steel (b), concrete (c), and masonry (d)

Most residential buildings are concentrated around the highly-populated province capital cities of Tehran, Tabriz, Esfahan, Mashhad and Shiraz. As observed, the more vulnerable types of construction (adobe and masonry) have expanded around Esfahan, Shiraz, Kerman, and in the southeastern corner of Iran by the Pakistan border. The more resistant classes of building such steel and RC have more prevalence in provinces of Tehran, East Azarbayjan (with Tabriz as capital city), Esfahan, and to some extent in Razavi Khorasan (with Mashhad city as capital). According to statistical analyses on the exposure data, about 55% of residential building in 2016 were made of modern construction materials such steel and RC, while the remaining 45% belonged to other types including masonry and adobe.

3.2.3 Vulnerability model

To estimate the damage ratio of exposed assets under a given earthquake scenario with known intensity parameters (e.g. PGA, PGV, or MMI), it is necessary to use vulnerability functions. These are typically functions or curves that relate various levels of hazard intensity to damage ratio or percentage for specified types of groups of assets (vulnerability classes). In this study, the vulnerability curves developed by Mansouri and Amini-Hosseini [38] as one of the components of the project Earthquake Model for Middle East (EMME) (Şeşetyan, et al., 2018) was used due to the reliability of the methodology used (RISK-UE) and the credibility of the main project (EMME).

These curves represent the seismic vulnerability of nine building classes of adobe (one class), masonry (two classes), steel (three classes), and reinforced concrete (three classes). Figure 3 exhibits examples of these curves for different types of building with medium-quality construction.

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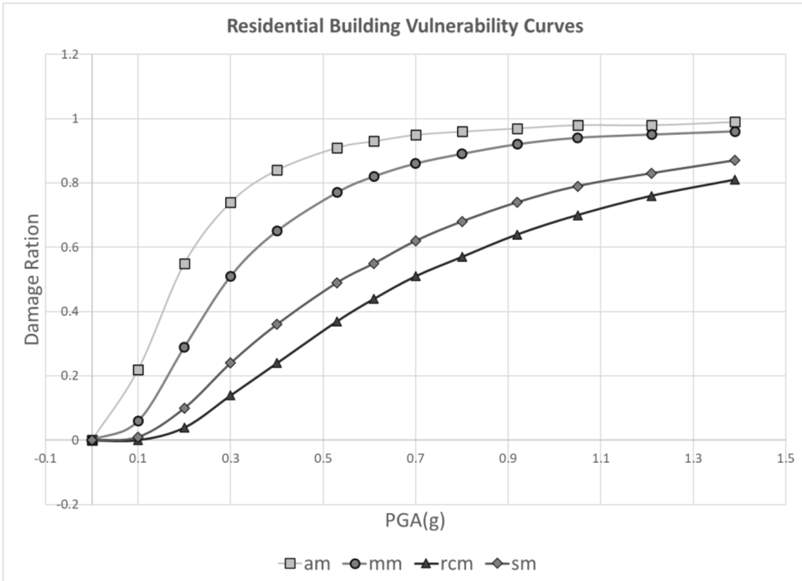

Figure 4 Vulnerability curves for medium-quality adobe (am), masonry (mm), reinforced concrete (rcm), and steel (sm) buildings

As shown in this diagram, adobe is the most vulnerable class of building to earthquakes, while RC and steel buildings offer the highest resistance to seismic loads. Masonry buildings fall within these two ranges.

4 Results and Discussion

After preparing the risk model components, a comprehensive event-based probabilistic seismic risk assessment for the entire country and risk results were generated. The results include risk metrics such as AAL and EP (99.5% confidence) for nine most-common classes of Iranian buildings. We utilised EP results for calculating the SCR of the chosen portfolio of residential buildings according to the Solvency-II Directive instructions. In parallel, the solvency capital of the portfolio was computed using the factor-based method introduced by the Iranian Directive No. 69. The section concludes with a comparative analysis between the current market earthquake premium rates in Iran and those calculated by the model, as well as a comparison between the Solvency-II and Directive 69 solvency capitals. In the end, some recommendations for enhancing the efficiency and accuracy of Directive No. 69 of the Central Insurance of Iran.

4.1 Earthquake Risk Assessment Results

Figure 4 shows the spatial distribution of seismic AAL aggregated at the county level. As observed, almost all parts of the country are exposed to medium and high levels of seismic risk, except for sparsely populated areas of central deserts and the northern coasts of the Oman Sea. There are also visible high-risk counties, especially around major cities of Tehran and Tabriz in northern and north-western Iran, as well as in other populated areas proximate to Mashhad (northeastern Iran), Esfahan (central Iran), and Ahvaz, Shiraz and Kerman in southern parts of the country. This pattern seems to be in accordance with the distribution of different classes of buildings and their exposure to

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the seismic hazard (please see figures 1 and 2); in areas with a concentration of buildings and very high level of earthquake hazard (such as in Tehran and Tabriz cities) the seismic risk is the highest. Similarly, we can witness a high potential of loss in the populated southern cities of Ahvaz, Shiraz and Kerman, that are subject to medium to high seismicity. The city of Esfahan, despite being located in a low seismicity zone, also shows high seismic risk solely due to its very high building exposure (the second-highest exposure value after Tehran) and the prevalence of more vulnerable building classes of masonry and adobe. In south-eastern Iran, where the province of Sistan and Baluchestan exists a high level of risk could be distinguished, mainly because of the existence of extremely vulnerable types of buildings (e.g. adobe) and despite the low concentration of built environment.

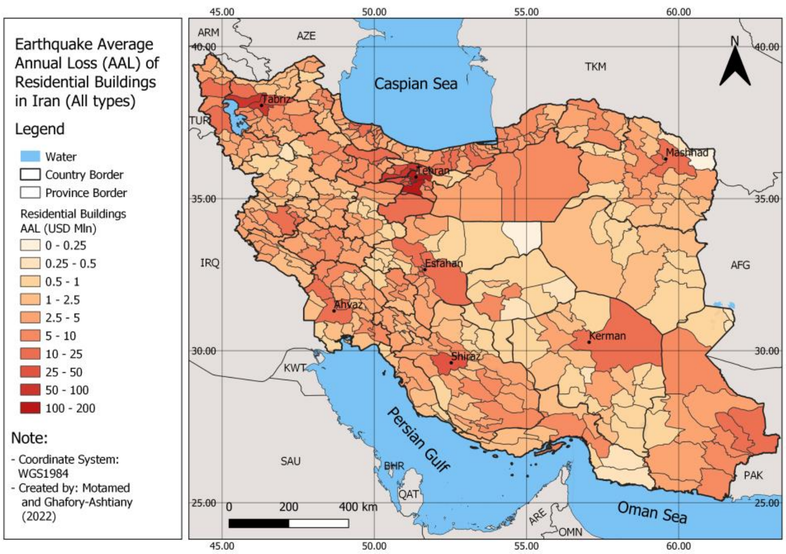

Figure 5 Earthquake Average Annual Loss (AAL) of residential buildings in Iran (million USD)

From what figure 5 presented as the spatial pattern of one-in-200-year losses of earthquakes in Iran, one could acquire an idea of the level of earthquake insurance capital required by the Solvency II regime for different types of buildings at the county level in Iran. Assuming a 100% insurance coverage for residential homes in Iran, the SCR or 1-in-200 loss for steel and RC buildings would be the highest in Tehran, Tabriz, and to a lower extent in Esfahan (and their surrounding counties). The situation is more homogenous for masonry structure (because of its prevalence in the entire country), where significant seismic losses with 99.5% confidence could be distinguished in almost all major cities in the country, namely Tehran, Tabriz, Mashhad, Esfahan, Kermanshah, and Kerman. In terms of adobe construction, again, a medium-to-high degree of losses could be expected in many counties except for areas located in Khuzestan and Fars provinces in the southwest. The only observable anomaly for 1-in-200 earthquake losses in adobe buildings is found in the country's most south-eastern counties in Sistan and Baluchestan province, particularly along the border with Pakistan. This pattern could be first due to the weighty number of absolutely vulnerable buildings made of adobe in these areas compared to other parts of the country. The second reason would be the eminent seismicity of this region, which is influenced by both shallow crustal and subduction seismic zones of Makran.

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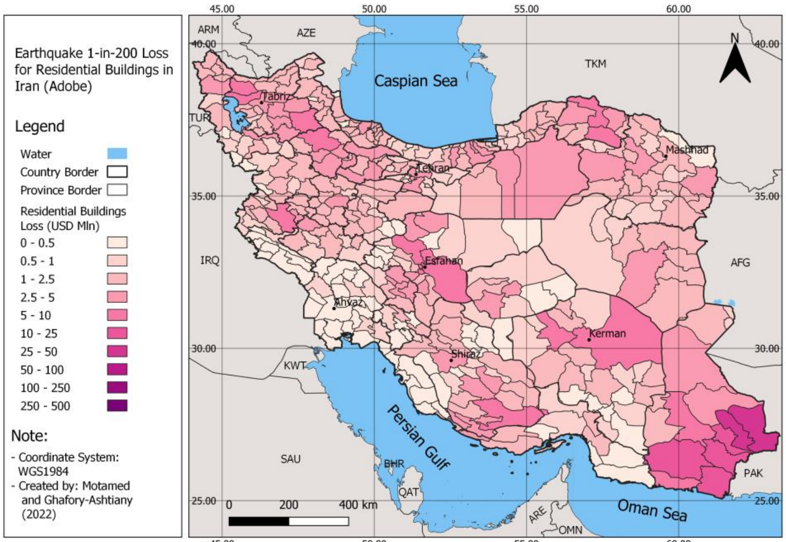
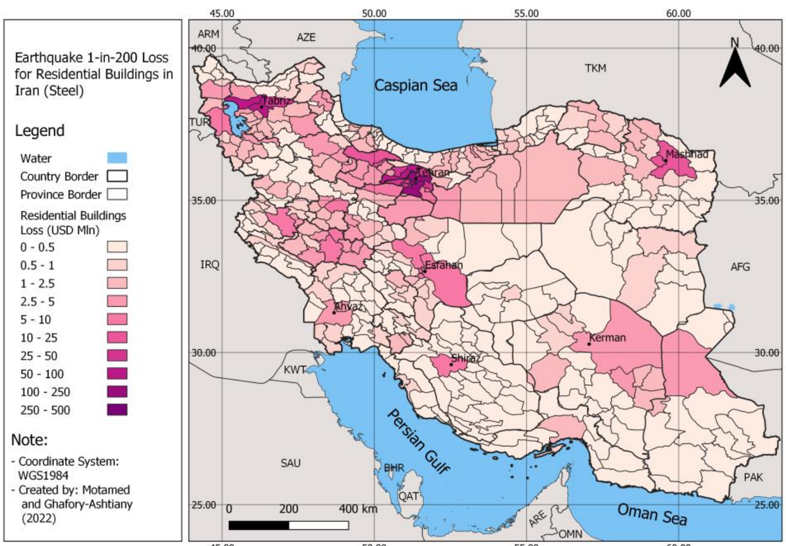


(a)



(a)

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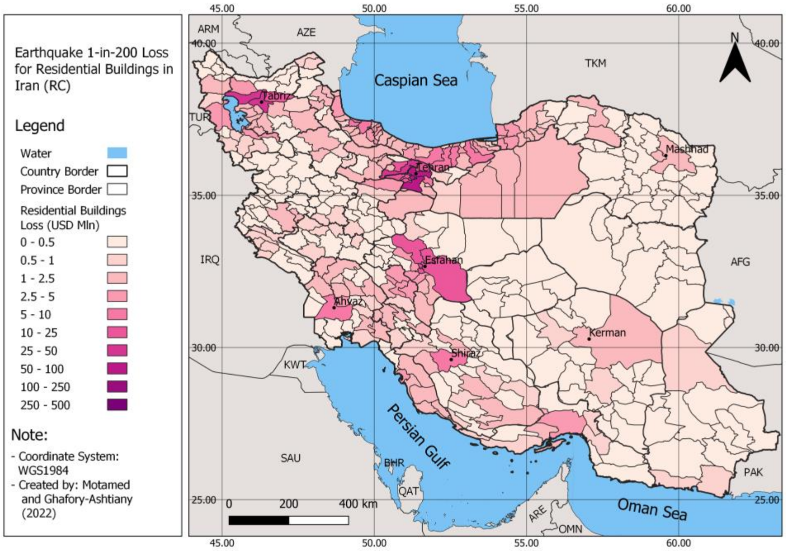
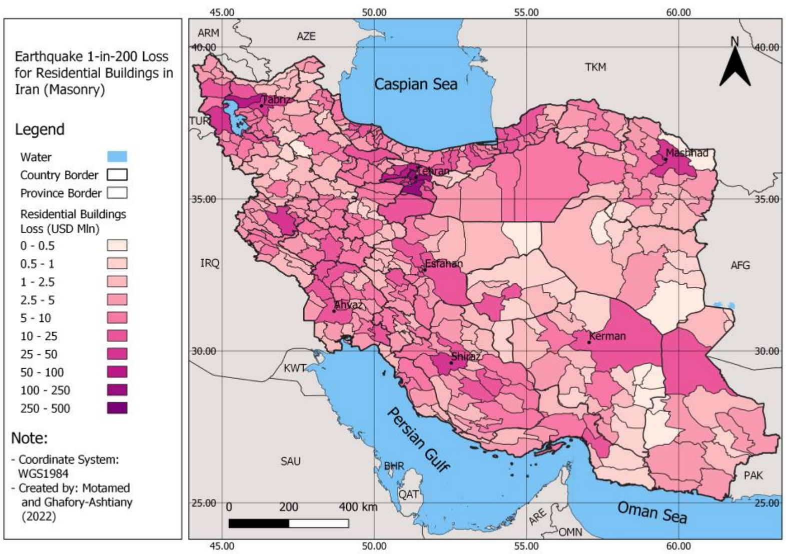


(c)



(d)

Figure 6: Earthquake 1-in-100 loss of residential buildings in Iran, adobe (a), steel (b), concrete (c), and masonry (d)

Table 2 presents the pure premium rate (AAL rate) of the same cities selected to compare solvency capital charges in Section 3. If we draw a comparison between these rates and those used for pricing earthquake insurance in the

Iranian market (Table 1), we notice a vast difference, implying a sizeable underestimation of earthquake risk in the Iranian insurance industry, including the supervising bodies like CII.

This difference is more pronounced for cities with a higher level of seismicity, such as Tabriz (the risk-based AAL is 7.89 times larger than the market premium for masonry buildings), even after neglecting the loading factors that are used to convert pure premium to technical premium. For seismically calmer cities like Esfahan, the discrepancy becomes milder, reaching a ratio factor of 0.63 for RC buildings.

Table 2: Risk-based (modelled) earthquake pure premium rates (in 1000) for different types of selected cities in Iran

Province	County	City	Risk-based earthquake pure premium rates		
			Masonry	Steel	Concrete
Tehran	Tehran	Tehran	7.15	2.01	1.65
East Azarbayjan	Tabriz	Tabriz	8.68	3.73	3.03
Esfahan	Esfahan	Esfahan	1.07	0.45	0.20
Kerman	Kerman	Kerman	3.35	0.90	1.04
Khuzestan	Ahvaz	Ahvaz	3.23	0.83	1.00

4.2 Calculation of Solvency Capital under Solvency-II and Directive 69

Having the earthquake risk results for 1-in-200 loss and the market premium rates for various types of residential buildings in Iran, now the solvency capital charge can be calculated at the county (or with an acceptable approximation at the city) level according to the methodology suggested by two different solvency regimes, namely Solvency-II and the Iranian Directive 69. At first, we consider a hypothetical portfolio of risks in five cities (counties) in Iran. It is assumed that 100 residential buildings of masonry, steel and RC types with a total built area of 100,000 m^2 are covered by earthquake policies in each of the selected cities in the country. The replacement cost for all types of buildings is supposed to be USD 300 according to the current market rates.

Unlike Directive 69, which uses an algebraic summation of spatially distributed risks, Solvency II employs a correlation matrix for aggregating risk capital at the portfolio level (national level). Therefore, we must first define a matrix at the province and country levels. Similar to the methodology provided in Annex IV of Directive (2009) and CEIOPS (2010), five simplified earthquake correlation matrices were defined for provinces where the selected counties exist and another matrix at the national level. The correlation matrices' values were determined based on the proximity of admin divisions (counties or provinces): each county has one correlation factor with itself and 0.5 with its neighbouring county. The same rules apply to the national correlation matrix. However, the correlation factor for the neighbouring province was chosen to be 0.25 due to the large dimensions of provinces in Iran. As an example, Figure A1 and Table A2 of Appendix indicates the configuration of counties in Tehran province and its corresponding earthquake risk correlation matrix based on the methodology suggested.

Table 3 shows the results of solvency capital calculation based on the two methodologies at the county, province and country for the hypothetical portfolio of risks.

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Table 3: Earthquake risk solvency capital based on the methodologies suggested by the Iranian Directive 69 (D-69) and Solvency II (S-II)

		Exposure (USD million)			D-69 solvency capital rates (x 0.001)			S-II solvency capital rates (x 0.001)			D-69 solvency capital (USD)	S-II solvency capital (USD)
Level		M	S	RC	M	S	RC	M	S	RC		
Location	Tehran	30	30	30	0.64	0.29	0.29	17.00	4.76	3.89	36,540	769,500
	Tabriz	30	30	30	0.64	0.29	0.29	17.25	8.65	6.00	36,366	957,000
	Esfahan	30	30	30	0.45	0.19	0.19	3.49	1.91	1.02	24,882	192,600
	Kerman	30	30	30	0.64	0.21	0.21	7.44	2.74	2.42	31,842	378,000
	Ahvaz	30	30	30	0.45	0.19	0.19	6.02	2.15	2.67	24,882	325,200
Portfolio											154,512	1,339,296

As seen in the table, there is at least a 20-fold difference between the solvency capital requirement in the Iranian financial supervision institution, CII, and Solvency II for the same portfolio of residential buildings in five distant cities of the country. Two drivers cause this discrepancy. The first is the difference between catastrophe capital rates in Directive 69 and the Solvency II system. The second reason for such difference is the absence of geographical diversification in the Iranian directive, which has a minor magnifying effect at the portfolio level. According to the rates exhibited in Table 2, the Solvency II risk-based rates are about twenty times the Directive 69 capital rates. As said, this gap is slightly alleviated when aggregating the solvency capital at the portfolio level because of the diversification applied in the Solvency II method. It is worth mentioning that the capital charges in the Iranian system are simply summed up in the geographical aggregation process. The final portfolio level catastrophe capitals for the Iranian and the European system are USD 154,512 and USD 1,339,296, respectively.

5 Conclusion

A numerical analysis was carried out in this paper to compare the methodologies described in the European Solvency-II regime and the Central Insurance of Iran for calculating the earthquake risk solvency capital. In the Iranian system, a constant factor is used to compute catastrophe charges based on each policy's earned premium and incurred losses. On the other hand, the Solvency-II Directive requires a catastrophe risk-based capital calculation for each location. There is also a difference between the two methodologies in risk aggregation: while the Iranian directive provides no specific method for aggregating capital charges (implying a simple summation), the European regime use diversification effect via correlation matrices. The earthquake risk capital charges calculated according to the two approaches reveal a considerable difference, with Directive 69 being about ten times smaller than that of Solvency-II.

Based on the analysis, it seems that the constant-factor approach adopted by the Central Insurance of Iran (CII) for calculating solvency capital for earthquake risks is substantially underestimated compared to the equivalent 1-in-200 capital size mandated by Solvency II. This can raise serious concerns regarding the ability of the Iranian insurers and reinsurers to withstand catastrophic shocks caused by medium to significant earthquake events in major cities in Iran. Although, due to the meagre penetration rate of insurance in Iran and the non-occurrence of medium to large events in main cities, no catastrophe-related insolvency has been witnessed in Iran, maintaining the current approach can compromise the insurance market in Iran and bring about the financial and social challenge in the face of future disasters. In addition, by the beginning of the Iran Building Catastrophe Insurance Pool (IBCIP), which provides primary insurance coverage for all residential buildings in Iran, insurance companies might find the market

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favourable to issue supplementary earthquake coverage for Iranian dwellings. If the insurance firms continue to use the current premium rates in such a situation, a significant accumulation of risk will occur again due to the vast exposure. Therefore, it is recommended that the insurance regulator in Iran initiate a transition from a constant-factor-based solvency system to a risk-based one or at least reconsider the current factors with those derived from the modelling of catastrophe risks.

6 Appendix

Table A1: Riskiness of different construction types in Iran (Ghafory-Ashtiany M. , 1991)

Type	Building Typology	Level of Earthquake Hazard				
		1	2	3	4	5
1	Adobe and Traditional	1.0	1.1	1.2	1.5	1.8
2	Confined Masonry	0.8	0.9	1.0	1.4	1.6
3	Pre-code Steel Structure	0.6	0.7	0.8	1.1	1.4
4	Pre-code Reinforced Concrete	0.4	0.5	0.6	0.8	1.0
5	Code Based Buildings Design and Construction (Post 1991)	0.2	0.3	0.4	0.6	0.8

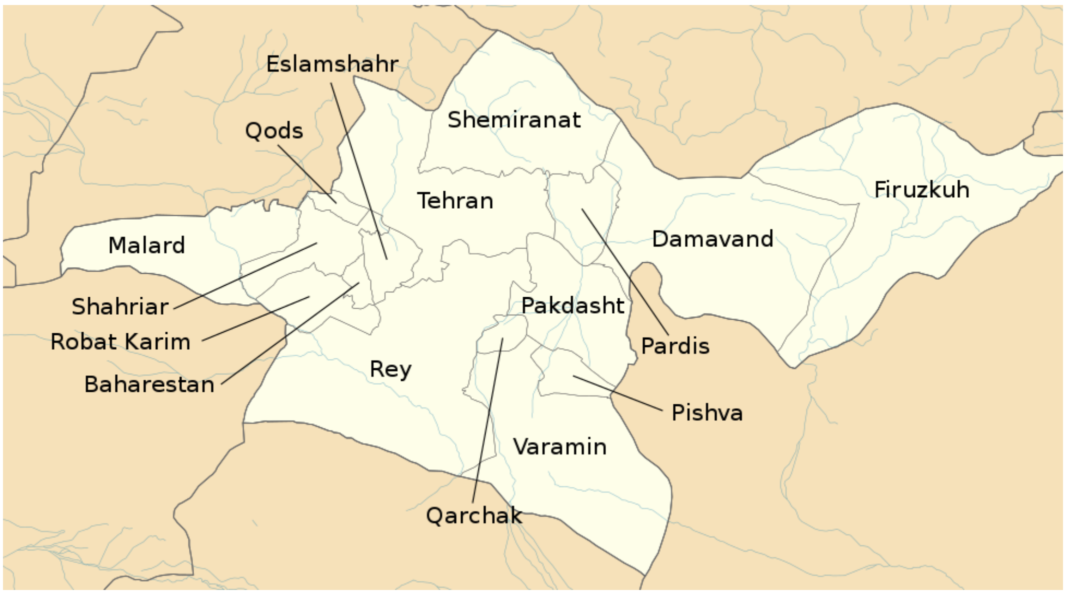

Figure A1: Tehran province and its counties

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Table A2: Earthquake correlation matrix for Tehran province based on the methodology suggested by Solvency-II

	Tehran	Shahriar	Eslamshahr	Baharestan	Malard	Pakdasht	Rey	Qods	Robat Karim	Varamin	Qarchak	Pardis	Damavand	Pishva	Shemiranat	Firuzkuh
Tehran	1															
Shahriar	0.5	1														
Eslamshahr	0.5	0.5	1													
Baharestan	0	0.5	0.5	1												
Malard	0	0.5	0	0	1											
Pakdasht	0.5	0	0	0	0	1										
Rey	0.5	0	0.5	0	0	0.5	1									
Qods	0.5	0.5	0.5	0	0.5	0	0	1								
Robat Karim	0	0.5	0.5	0.5	0.5	0	0	0	1							
Varamin	0	0	0	0	0	0.5	0.5	0	0	1						
Qarchak	0	0	0	0	0	0.5	0.5	0	0	0.5	1					
Pardis	0.5	0	0	0	0	0.5	0	0	0	0	0	1				
Damavand	0.5	0	0	0	0	0.5	0	0	0	0	0	0.5	1			
Pishva	0	0	0	0	0	0.5	0	0	0	0.5	0.5	0	0	1		
Shemiranat	0.5	0	0	0	0	0	0.5	0	0	0	0	0.5	0.5	0	1	
Firuzkuh	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	1

7 Data Availability

Data used in this research are the intellectual property of Iran National Science Foundation who funded the study and cannot shared by the authors.

8 Authors Contribution

In the preparation of this report, Prof. Mohsen Ghafory-Ashtiany has planned the research project and contributed to the content of different chapters mainly in the earthquake hazard and risk assessment and modelling and review and validation of results. Dr. Hooman Motamed has been mainly responsible for authoring the insurance regulation content and numerical analysis. Both authors have equally edited the final manuscript.

9 Competing Interests

The contact author has declared that none of the authors has any competing interests.

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