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Vulnerability Assessment of R/C Buildings for Earthquake Insurance Purposes

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Abstract: - A concrete mitigation measure is seismic insurance cover of buildings creating conditions of risk burden sharing between public and private sector. The multivariability of the seismic phenomenon and the lack of communication between insurance companies and structural engineers has not allowed until today the development of the particular sector. However, for this branch to be developed, new methods are needed to be introduced in order to record the actual intend of the building to damage, considering the specific structural characteristics of each building. Today's approach to this problem becomes according to the map of seismic hazard zones and of how old a building is. A practical evaluation methodology is proposed for the seismic vulnerability of the exposed value (property/public work) to be insured, according to the rapid seismic visual screening philosophy. An application to Greek circumstances is made.

Key-Words: -Earthquake insurance, vulnerability assessment, asset-screening methodology, Greek application

1 Introduction

We recognize notable earthquake insurance systems in Japan, California, New Zeeland and Turkey [1]. Unfortunately, in Europe and especially in Balkan region there is no such a system despite the fact that there are countries with high seismicity (Greece, Romania, etc). The complexity of the seismic phenomenon and the lack of communication between state's decision makers, insurance companies and structural engineers has not allowed until today the development of the particular sector.

Earthquake risk is assumed by insurance and reinsurance companies. In general financial institutions have not until recently begun talking to the structural engineering community who possess the earthquake mitigation tools. Today, people of the seismic insurance deals mostly with the criteria which involve only financial and seismological characteristics without taking under consideration the conformation of a structure which directly or indirectly introduce the parameter of the structural behaviour. In this context, in order to evaluate the seismic risk one of the parameter is the seismic hazard of the region and the other is the vulnerability of the exposed values. Once, obtaining the seismic hazard which definitely exists in a particular region of great importance is the vulnerability of the buildings within this area, in other words the excepted structural damage which should cover the insurance company. The key parameter is the predisposition of a building to collapse which is described by the structural conformation, building age, maintenance of building, possible structural transformations, vicinity with a gas system, etc. It is well known that in the same seismic zone there are structures with different vulnerability. Furthermore, there is a possibility for structures with the same vulnerability to behave in a different manner in the same earthquake intensity. Vulnerability curves and damage probability matrices are general estimators without taking into account the specific characteristics of each building. For earthquake insurance purposes it is more convenient to use an asset-screening methodology, which describes the actual condition of a structure. The protection and the increased profit of the insurance company is possible to come from a certified methodology which at first evaluates with speed and reliability the probable behaviour of the building for damage according to the structural characteristics of the building in conjunction with the seismicity and geotechnical characteristics of the region, on which is based the further financial approach for the improvement of the insurance product.

At the current paper a methodology for the evaluation of the seismic vulnerability of R/C structures is described in two levels, based on the asset visual screening process [2] and introducing also the knowing level of the person who is running the valuation check (Insurer, Engineer) as well as

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the greatness of the hazard to be insured. The methodology is applied to the Greek design circumstances [3].

2 Methodology for the vulnerability assessment of r/c buildings

The basis of the suggested process is on the philosophy of rapid visual screening [2] suitable adjusted to the level of performance-based design of [3]. In such a way an easy view of the structural factors which increase the risk of failure through a quantification approach is used. The methodologies are described in two levels: one simple and one compound taking under consideration the level of the covered risk to be insured as well as the level of knowledge that the person who do the evaluation has. In reference to the above it can be stipulated that:

i. Vulnerability Insurance Card (building/apartment) of the exposed property. Evaluation from a properly trained insurer. It is proposed for the use of low insurance risk.

ii. Vulnerability Insurance Envelope of the exposed property. Evaluation from a proper trained engineer. Proposed for the use in high insurance risk.

2.1. Vulnerability insurance card

It is based on typified check lists, (Table 1, 2), which fulfilled by the insurer after a discussion with the insured (e.g. demonstration of property document, structural permission, etc) and rapid visual screening of the property. The calculation is occurred in two steps. The evaluation philosophy is based on the consideration that the property has a current rate from which points are removed according to the factors of seismic vulnerability. The final score is arising according to which the insurance rate is calculated. Grading scale 0–300 points. Grading limits: 300–220 points, Low Hazard (LH), 220–180 points, Mid–Hazard (MH), 180–0 points, High Hazard (HH). The evaluation of vulnerability parameters is given to the Table 2 using the concept the Partial Criteria of Seismic Vulnerability, PCoSV. The grades of vulnerability are predetermined because here the insurer do not have the appropriate level of knowledge. The method is fast, based on questionnaires, and do not require sophisticated knowledge and as a result with low training cost of the people who do the valuations. Definitely the training is necessary, which will be included by simple examples, reading ''recipes'' of the partial criteria of seismic vulnerability. More analytically, is included:

i. *I.D. of the Insured Property.*
Divided in 4 parts (Ownership, Technical Characteristics, Ranking of the insurance rate). It covers basic ownership elements, technical elements of the way the property constructed, and finally refers to the cost given for the insurance rate. Furthermore, the elements of the index will be used in case that after an earthquake damages will reveal and the insurance company will be called to cover the insurance rate.

ii. *Basic Criteria of Seismic Vulnerability.*
Includes basic vulnerability criteria, which are likely to provoke the damage predisposition of the insured property combining the construction year–construction regulation and the seismic hazard zone. According to the basic elements of the property the origin rate of seismic vulnerability is extracted, Table 1. The identification of the construction regulation is based upon the year that the structural permission was issued.

iii. *Partial Criteria of Influence. Final grading–Extraction of Seismic Vulnerability.*
Includes the special structural abilities of each building, in the way that they affect the seismic predisposition for damage according to the international bibliography [4], [5], in conjunction with the construction year and independently from the seismic hazard zone. The final mark of the seismic vulnerability is extracted (High (H), Medium (M), Low(L)) Table 2, according to whom the cost of the premium will be calculated.

As a result from Table 1 the Initial Mark of Insurance Vulnerability, can arise, (IMIV), while taking under consideration the initial influence of the construction year (through the used code) as well as the zone (SHZ) in which the estimated value is placed. Table 2 introduces the Partial Criteria of Seismic Vulnerability, (PCoSV), as these are recorded by the insurer while he is screening-evaluating the property to be insured. The Initial Mark of Insurance Hazard (IMIH) reduced by the (PCoSV) provides the Structural Risk (SR), with which the premium of seismic cover will be evaluated.

Short example: Building of which the structural permission was issued in 1980 and it is located in Thessaloniki–Greece, (IM= 300 points , Building CD2 = -40, Zone II, BIM = -30).
Table1--IMIH=300-40-30=230points.Assuming that the building has PCSV-2: -10 Points, and PCSV-3: -15 Points, (from Table 2). PCoSV = -10-15 = -25.

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So, SD = (IMIH) – (PCoSV) = 230 – 10 – 15 = 205 points. The building ends up to have a medium structural vulnerability which leads to a medium insurance danger. With the aforementioned process was determined the vulnerability parameter. For the computation of the pure risk premium remains to determine the seismic hazard parameter with a proper methodology. Undoubtedly, the insurance company should proceed a financial risk analysis in order to prevent possible insolvency.

Table 1. Basic ranking criteria of estimated exposed value (Building Construction: R/C)

Estimated Property	Initial Marking	Basic Criterion of Seismic Vulnerability		Basic Influence Mark	Seismic Hazard Zone	Mark of Zone Influence
(EP)	**(IM)**	**(BCoSV)**		**(BIM)**	**(SHZ)**	**(MoZI)**
BUILDING	**300**	***CD1***	Regulation Of Reinforced Concrete 1954	- 50	I	- 20
		CD2	Regulation Of Reinforced Concrete 1954 Seismic Regulation 1959	- 40		
APARTMENT		***CD3***	Regulation Of Reinforced Concrete 1954 Seismic Regulation 1984	- 30	II	- 30
ESTABLISHMENT BASEMENT STORE		***CD4***	Regulation Of Reinforced Concrete 1991 Seismic Regulation 1984/1992	- 20		
		CD5	Regulation Of Reinforced Concrete 1991 Seismic Regulation 1992/1995	- 10	III	- 40
		CD6	Regulation Of Reinforced Concrete 2000 Seismic Regulation 2000	0		

Table 2. Partial marking criteria of evaluated exposed value (Building Constructions R/C)

Nr.	Partial Criterion of Seismic Vulnerability	Structural regulation- Construction year					
	(PCoSV)	Until the 1954 **CD1**	1954 - 1964 ***CD2***	1985 - 1991 ***CD3***	1992 - 1995 ***CD4***	1996 - 2000 ***CD5***	2001 – … ***CD6***
PCoSV-1	Actual state of the building	-15	-15	-10	-5	-5	---
PCoSV-2	Previous seismic charges	-15	-10	-5	-5	-5	---
PCoSV-3	Existence of pilotis Existence of lobbies in the basement	-15	-15	-15	-15	-10	-5
PCoSV-4	No existence of underground Basement	-15	-10	-10	-10	-5	-5
PCoSV-5	Existence of intermediate floor with	-15	-15	-15	-15	-10	-5
PCoSV-6	Conformation of building in plan	-15	-15	-15	-10	-5	-5
PCoSV-7	Buildings Height-Setbacks	-15	-10	-10	-5	-5	---
PCoSV-8	Distance from nearby buildings	-15	-10	-10	-5	-5	---
PCoSV-9	Passage of pipes Drainage, Sewerage Water supply at the maze of columns, walls	-15	-15	-15	-10	-5	-5
PCoSV-10	Use Change/ dispositions of the building / apartment	-15	-10	-10	-10	-5	---
PCoSV-11	Existence of heavy façade elements	-15	-10	-10	-5	-5	---
PCoSV-12	Building connected with natural gas network	-15	-15	-15	-15	-15	-15
PCoSV-13	Internal existence of dangerous inflammable material	-15	-15	-15	-15	-15	-15
PCoSV-14	Existence of Fragile material of high value in the internal of the apartment or/and building apartments	-15	-15	-15	-15	-15	-15

High Vulnerability Criterion, (H): -15 Points
Medium Vulnerability Criterion, (M): -10 Points
Low Vulnerability Criterion, (L): -5 Points
High Structural Vulnerability: $0 < SV \leq 180$ Points → High Insurance Danger

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Medium Structural Vulnerability: 180 < SV ≤ 220 Points → Medium Insurance Danger
Low Structural Vulnerability: 220 < SV ≤ 300 Points → Low Insurance Danger
Structural Vulnerability, SV

2.2. Vulnerability insurance envelope

Generally, the consequences of the seismic risk or the consequences of the seismic impact are depended by the seismic hazard, the evaluated value (of the property) and its vulnerability. The Earthquake Engineering Research Institute of Berkeley in the text Understanding Risk Management, 2000, refers to the below necessary elements for the quantification of the seismic risk:

i. Property description (activity) in which is exposed and for whom the quantification of the seismic hazard takes place.

ii. Calculation of the damage mark for all the different possible scenarios.

iii. Quantification of the damage that will arise as a direct or indirect result of the possible failures as well as the loss of property usage (activity).

By taking under serious consideration the above fundamental principles a simple methodology is suggested, which is structured by standardized, tables and forms, in order to be used from a Structural Engineer, after receiving the appropriate training. The evaluation philosophy is similar with above mentioned in paragraph 3.1, although the vulnerability criteria are evaluated on basis of the principals of the Structural Engineering's Science, Table 3,4,5. In that case the Structural Engineer decides–evaluates the vulnerability mark, through a simple calculations process, taking the vulnerability criteria from Tables 4, 5. It should be noted that the appraisal criteria follow the level of performance of [3], while their choice is according to the experience of recorded seismic failure, [4],[5]. Tables 4,5, specifying the quantity criteria as well as the quality criteria which increase the degree of reliability of the predictions–evaluations. More analytically it can be said that every evaluated value, in this case r/c buildings, comprehends a first starting total marking, 180 points, Table 3. This marking is gradually decreased while introducing the basic vulnerability parameters as structural system, design regulation, seismic hazard zone, and afterwards the partial vulnerability factors as the existence of pilotis, vertical non regularity, etc, as they are recorded by the asset screening process. Finally the structural risk is assessed in basis of which the insurance risk will be calculated. The graduation is becoming in three stages High, (H), -15 points, Medium, (M), -10 points, low, (L), -5. The boundaries that characterizing the insurance vulnerability are given in the follow:

High Structural Vulnerability: 0 < SV ≤ 125 Points → High Insurance Danger
Medium Structural Vulnerability: 125 < SV ≤ 160 Points → Medium Insurance Danger
Low Structural Vulnerability: 160 < SV ≤ 180 Points → Low Insurance Danger

An important clue for the correct evaluation of the vulnerability is the enactment of boundaries that characterize the appreciated structural vulnerability. Assuming that the quality-quantity criteria of table 4,5 leads to the reduction of the systems rigidity, strength and ductility, the conventional criterion is taken under consideration from the assumption of NZS 4203, 1984, where is defined that when the fall of the strength of a structural element (structural system) is more than 30% it is likely to lead to failure. Generally speaking, it is appreciated that the reduction of the origin total marking of the evaluated value over than 30% is likely to lead to high structural danger and therefore into high insurance risk.

The application of this method requires checks in the field from an engineer, discussion with the person to be insured, visual screening of the property, and supplementary collection of elements from the origin project. After the end of the checks the vulnerability is validated and the cost rung of the premium is calculated. It is possible to cover the damaged building property, the loss of contents or both. An envelope with the full identification elements of the project should be developed, taking under consideration the fact that current methodology is used for the insurance of projects of high seismic risk (e.g. Project ID, findings of the on site investigation of structural and non-structural elements, information concerning seismological, geotechnical, structural and non-structural conditions, vulnerability assessment of the insured property. It is evident that the aforementioned process, as compared with the other one presented in paragraph 2.1, should be used when insured properties are very important (such as museums, etc) or the value of the building and its contents is very high (such as bank buildings, etc).

3 Conclusions

The earthquake insurance cover is a basic need for modern society. This is especially true to developing countries, or in case of financial crisis where the economics of States are fragile. The

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suggested practical methodology in two levels, according to the insured risk to be covered, is based on earthquake engineering theory, practical engineering experience and observed seismic damage from past earthquakes.

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Table 3. Basic Marking Criteria of Estimated Value (R/C Buildings)

Estimated Property	Origin Marking	Marking of Building System (MoBS)			Basic Influence Mark	Seismic Hazard Zone	Zone Influence Mark
(EP)	**(OM)**	**Crt.**	**Description**	**Design Regulation**	**(BIM)**	**(SHZ)**	**(ZIM)**
Reinforced Concrete Buildings	**180**	**MoBS-1**	Building with Frame	Regulations Concrete 1954 Seismic 1959	-15		
		MoBS-2	Building with Frame + Shear Walls	Regulations Concrete 1954 Seismic 1959	-15	I	-5
		MoBS-3	Building with Frame	Regulations Concrete 1954 Seismic 1959 Additional articles 1984	-10	II	-10
		MoBS-4	Building with Frame + Shear Walls	Regulations Concrete 1954 Seismic 1959 Additional articles 1984	-10		
		MoBS-5	Building with Frame	N.E.A.K. N.E.K.Ω.Σ.	-5	III	-15
		MoBS-6	Building with Frame + Shear Walls	N.E.A.K. N.E.K.Ω.Σ.	-5	IV	
		MoBS-7	Without Seismic Regulation / No Building Permission		-180*		

Table 4. Partial Marking Criteria of the Estimated Value (R/C Building)

Nr.	**Vulnerability Criterion**	**Vulnerability Grade**		**Structural System**
1.	Floor Mechanism / Short columns at the ground floor level (Pilotis)	L M H	-5 -10 -15	**MoBS-1** **MoBS-2** **MoBS-3** **MoBS-4** **MoBS-5** **MoBS-6** **MoBS-7**
2.	Pounding	L M H	-5 -10 -15	
3.	Previous Seismic Actions	L M H	-5 -10 -15	
4.	Bad condition due to lack of maintenance / low construction quality	L M H	-5 -10 -15	
5.	Change in Use / Add without permission	L M H	-5 -10 -15	
6.	Vertical non regularity	L M H	-5 -10 -15	
7.	Horizontal non regularity	L M H	-5 -10 -15	
8.	Torsion Possibility	L M H	-5 -10 -15	
9.	Floors with Short columns Not continuous Load Paths	L M H	-5 -10 -15	
10.	Soil B		-5	
11.	Soil C,D,X		-10	
12.	Soil C,D,X and 5 floors over		-15	

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Table 5. Quantification of Partial Vulnerability Criteria

Nr.	Vulnerability criterion	Marking criterion
1.	Floor Mechanism / Short columns at the ground floor level (Pilotis)	(H): MoBS-1, MoBs-2, MoBS-3,MoBS-7. (M): MoBS-3. (L): MoBS-5, MoBS-6.
2.	Pounding towards buildings nearby	(H): Cases where there is no joint between buildings. Cases of corner buildings. (M): Cases where there is a medium difference in stiffens between two buildings. (L): Cases with small aseismic joint not respecting the codew prescription [7].
3.	Previous Seismic Actions	(H): Characterization by previous earthquake Red (post seismic damage mark). (M): Characterization by previous earthquake Yellow / Orange. (L): Characterization by previous earthquake Green.
4.	Bad situation due to lack of maintenance / low construction quality	(H): Validation by the on site screening process. (M): Examples of bad maintenance: Corrosion of reinforcement, fissures due to (L): settlements, signs of poor workmanship, fissures on masonry, etc.
5.	Change in Use / Add without permission	(H):Change or transformation of the initial structural system. Additional loads, loads not taken under consideration during the first design. Change of importance category.
6.	Vertical non regularity	<u>Qualitative Criteria:</u> (H):Different level foundation. Non continuous and non regular distribution of vertical elements, short columns except pilotis. Building typeMoBS-7. (M): Joint between different level foundation or between vertical elements. (L): Buildings designed and constructed according to [7] (MoBS-6). <u>Quantitative Criteria:</u> (H): Mass Change $\Delta mi>0.50$. Stiffness change of layer $\Delta Ki>0.50$. (M): Mass Change $0.35<\Delta mi<0.50$. Stiffness change of layer $0.35<\Delta Ki<0.50$. (L): Mass Change $\Delta mi<0.35$. Stiffness change of layer $\Delta Ki<0.35$.
7.	Horizontal non regularity	<u>Qualitative Criteria</u> (H): Complex shape buildings L,E,Π,T., Buildings with $L_{max}/L_{min} > 4$. Buildings with external sides under acute angles. Intense geometrical anomalies in plan. Indirect connections between elements. Building type MoBS-7. (M): Structural r/c walls changing according to height of building. (L): Buildings designed and constructed according to [7] (MoBS-6). <u>Quantitative Criteria</u> (H): $d(CM\text{-}CR)>0.35L_{min}$ (M): $0.20<d(CM\text{-}CR)<0.35L_{min}$ (L): $d(CM\text{-}CR)<0.20L_{min}$.
8.	Torsion Possibility	<u>Qualitative Criteria</u> (H):Non symmetrical arrangement of structural r/c walls. Building type MoBS-7. (M): Structural r/c walls changing according to height of building. (L): Buildings designed and constructed according to [7] (MoBS-6). <u>Quantitative Criteria</u> (H): Percentage 50% of short columns into a middle floor. Non continues columns (M): Percentage 35% of short columns into a middle floor. Non continues columns (L): Percentage 20% of short columns into a middle floor. Non continues columns.
9.	Lack of diaphragm action	<u>Qualitative Criteria</u> (H): Different level of plate in the same story. Corner holes, or in general large openings. Inadequate connection with vertical elements. Building type MoBS-7. (M): Lack of under ground basement. Setbacks creating weak zones. (L): Buildings designed and constructed according to [7] (MoBS-6). <u>Quantitative Criteria</u> (H): Holes in a story of more than 35% of the total story area. (M): Holes in a story of no more than 25% of the total story area. (L): Holes in a story of no more than 15% of the total story area.
10.	Soil B	(L):Soil category according to [7].
11.	Soil C,D	(M), (H): Soil category according to [7] / Elaborate geotechnical study.
12.	Near fault	(H): Necessity of elaboration of geotechnical study.

Using the aforementioned methodology it is easily responded the question of how a structure is designed and constructed in order to resist the expected earthquake. In this context providing to the insurance company the vulnerability parameter whish is necessary for the assessment of pure risk premium rate.

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