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INCORPORATION OF INSURANCE RATE IN THE SEISMIC DESIGN OF BUILDINGS

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ABSTRACT: Buildings damage and loss estimation methods, LEM, have been developing at a fast pace in the last few years. Recent advances in Ground Motion Prediction equations, site response analyses, and Fragility Curves for buildings provide valuable tools for structural design based on social and economic losses, as is presented in the latest Performance Based Earthquake Engineering, PBEE, procedures developed by FEMA. However, the issue of how to incorporate criteria based on social or economic losses for design, i.e. what type of new performance objectives can be used, has been less explored. Understanding annualized losses and insurance rates at both levels, for individual buildings and also for a set of properties is essential to propose design, performance based, criteria. Other aspects like the difference between insurance technical and commercial rates can be significant for selecting new performance based design parameters. The interaction between Reinsurance and Insurance can also be important for suggesting philosophies of design based on losses. This paper works in the following directions: First, it highlights the need of new performance based design objectives/criteria. Second, after clarifying how the risk framework is embedded in the most recent PBEE methods, it makes clear, technical and commercial issues related to insurance and reinsurance premiums and rates. Third, it uses the most advanced state of the art software, for estimating losses and its associated frequencies in order to highlight the process of structural design based on losses. Finally, it provides suggestions related to Loss based structural design, i.e. new performance objectives, that can be implemented in Seismic Codes.

1. Introduction

Yearly, social and economic losses due to earthquakes continue causing a large burden on society world-wide. Just in 2014 there were 847 fatalities and US$0.6 billion in total economic losses due to the occurrence of seismic events around the globe (Munich Re, 2015). Losses linked to natural phenomena remain showing a steep ascending trend according to data recorded by the international re-insurance sector (Munich Re, 2015). Causes of this growth of losses can be analysed following the well-known framework of risk, i.e. the effect of the interaction between hazards, vulnerability and exposure. Risk can be understood as the effect of uncertainty on different social and physical elements, and therefore it is not strange specifying/modelling risk as a relation between losses, and annual frequencies or probabilities. Let us examine first the three main components of risk in more detail. Seismic *hazard* is evolving as more knowledge is acquired and we start including updated data in recent seismological models, e.g. Halchuk, et. al. (2014). Some estimated ground motions following those new models might increase as compared to those of former methods, while others can decrease. However, from the perspective of a hazardous phenomenon, it is not so simple to argument that the trend observed in losses can be strongly attributed to a marked overall increase in hazard. Note, for example, that it is uncommon observing a significant increase in the long term recurrence rates of earthquakes of some magnitude (provided that a catalogue is complete in the period of analyses).

Seismic *vulnerability* can be responsible for significant damage and losses, as was the case of the 31 March, 1983, Popayán, Colombia, M=5 earthquake, where most of the old colonial, adobe type, buildings in the city downtown collapsed (as one of the authors personally observed). A recent example of the effect of low vulnerability on losses is the tragic April, 2015, M=7.8 earthquake, occurred in Nepal, where, until the moment of writing these lines, the death toll surpasses 7,000, most of them buried below buildings debris (NBC-News, 2015). Despite those tragic events, it is expected that the obligation of using Building Codes at those places where they are not yet mandatory, on one hand, and the evolution of the most advanced Codes, on the other, will significantly contribute to decrease future losses.

The third component of the risk framework, *exposure*, includes the social, economic and monetary values of the elements subjected to hazards, irrespective of their vulnerabilities. The nature of exposure multiplies the effects of individual vulnerabilities subject to the hazard. Therefore, it amplifies the potential/expected losses proportionally. A direct parameter that characterizes exposure is human population, the effect of which is at least double: first, people produces/increases the number of economic assets (buildings, etc), including technological elements, like electronic equipment. Second, it increases the potential for casualties. Then, it is not surprising that a graph of population change for a region can be considered as a figure showing the variation of the potential for loss or risk, regardless of the level of vulnerability or building code vintage implemented. Figure 1 was prepared using data from statistics Canada (Statcan, 2015). Population data for the province of British Columbia, Canada, between years 1867 and 2014 was compiled. The steep change from 32,000 to 4.6 million inhabitants shows a dramatic increase in population and therefore in potential losses and risk in British Columbia by a factor of 145 during the last 150 years.

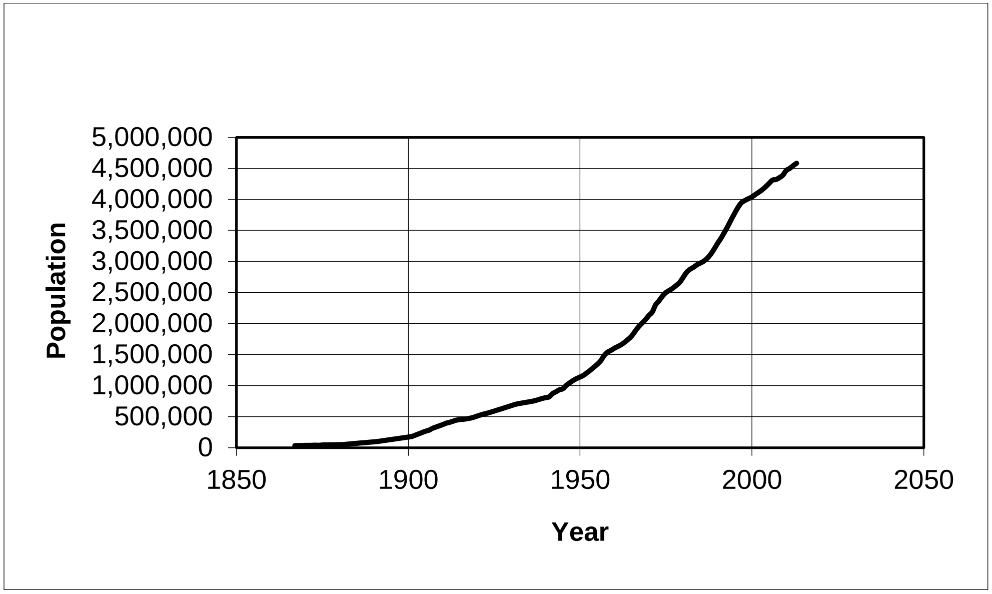

Fig. 1 – Population (loss potential, risk) growth in British Columbia, 1867-2014.

Despite the natural expression of social and economic losses in casualties and monetary terms engineering design is not yet directly related to those parameters. Codes philosophies are generally based in criteria like:

- Preventing major failure and loss of life.

- Structures should be able to resist moderate earthquakes without significant damage.
- Buildings cannot collapse.

However, there are not quantitative, more objective, measures of the meaning of those philosophies, in the present codes. The language used in the codes is not useful for decision makers involved in planning and/or in the process of doing financial or social mitigation, i.e., current codes languages are disconnected from the general terms used in risk management. Questions like what are the expected repair costs, financial losses, repair time, unsafe placards, injuries or casualties, and their level of uncertainty, i.e. the probabilities/frequencies in the estimations, are not directly addressed in present codes. Recall, for example, that general accepted levels of seismic hazard, e.g. ground motions with period of returns of 2,475 years, do not say anything about the corresponding accepted level of damage and social or economic losses in a quantitative and objective manner. Other specific issues like what is the expected, average, annual loss, and whether the tools for financial mitigation, e.g. using insurance, are enough to financially cover a building against earthquake losses cannot be addressed using current design parameters. Clearly, it is not possible doing financial mitigation of earthquake risks without known expected losses and their probabilities; therefore we do not know, for example, if the current insurance rates are over or under estimated. In the case that the insurance rates are insufficient to cover the risks, it is not possible to know what fraction of the earthquake risks are being covered just using parameters calculated following methods given in the current codes. The potential for under-covering earthquake risks from a financial perspective is not an issue that concern the insurance or re-insurance sector only, because if the insurance sector is not able to pay losses after a large event, the risk is translated back to buildings owners. Other questions like whether it is financially advantageous to do a seismic upgrade cannot be solved with the design parameters provided according to the procedures stated in current codes. The before mentioned significant shortcomings of the current codes could be addressed and solved using the tools already available following the advances in Performance Based Earthquake Engineering, PBEE, methods, which allow estimating social and economic consequences and their associate frequencies/probabilities.

As there is uncertainty in nature, a logic approach to deal with quantitative, objective, measures of earthquake consequences is using the risk framework to express the level of safety wished by the society. Utilizing risks concepts also facilitates the use of social and economic indicators needed in the process of taking informed decisions. The risk framework is embedded in the latest advances of Performance Based Earthquake Engineering, PBEE. This document highlights several of the tools already available in the risk based concepts and framework, providing suggestions to complement the current structural design procedures.

2. Concepts and risk framework

2.1. Current performance based earthquake engineering, PBEE, and the risk framework

A complete description of the advances and current state of PBEE is available at FEMA (2012), where results of the project FEMA P-58, Seismic Performance Assessment of Buildings, prepared by the Applied Technology Council, ATC, are included. The FEMA P-58 documents describe and recommend procedures to assess the probable seismic performance of individual buildings based on site, structural, non-structural and occupancy characteristics. Performance is measured, using the risk framework, in terms of the probability of incurring casualties, repair and replacement costs, repair time and unsafe placarding. The procedures applies for new or existing buildings and can be used to either assess the probable performance of a building, or design new buildings to the level of performance desired, or design earthquake upgrades of existing properties. The performance-based design starts with selecting performance objectives (damage states, losses, probabilities, casualties, etc., in general, statements of the accepted level of risk) wished by a wide number of stakeholders like developers, owners, lenders, insurers, etc. Once performance objectives are selected engineering analyses/designs are executed to determine performance capability. This process is called performance assessment. If the assessed performance is equal to or better than the performance objectives, the designs are correct. Otherwise the designs are reviewed and the process continue iteratively until the objectives match. Following the current PBEE state-of-art given in the FEMA P-58, performance assessment incorporates the risk framework applying the total probability theorem through a multi-level integral to predict earthquake consequences and its associated frequencies/probabilities (performance). The process uses all the seismic hazard available, site specific soil conditions, structural characteristics (vulnerability, fragility curves, etc.).

2.2. Average annualized, insurance, rates and loss

Traditional engineering design refers to damage which in general is understood as displacement demands, its effects, and its physical description grouped in *damage states*. The current risk framework, embedded in PBEE use losses which refers to the social, casualties, or the economic, monetary, quantification of damage.

The average annualized loss, AAL, can be defined as:

$$AAL = f_1 * L_1 + f_2 * L_2 + \cdots + f_n * L_n \tag{1}$$

Where f_i are the annual frequencies of occurrence of losses L_i, n is the number of data considered for the analyses (the higher the better). Note that the specific losses are equivalent to the vulnerabilities under the general risk framework, while, on the other hand, the frequencies are not the seismic hazard values, but could be called the hazard of the losses. One of the problems to incorporate losses into the engineering design is that when there is not enough statistical data available, the usual case for earthquakes, the frequencies of losses are highly complex, non-linear, functions depending on tectonic, general and local geology, hydrogeology, and structural parameters. However, this shortcoming is being solved at a fast pace due to results of research and the general availability of fast and high memory capacity computing systems, as has been shown by the FEMA P-58 project (FEMA, 2012).

The average annualized rate, AAR, which is the same as the technical insurance rate, TIR, is the ratio between the average annualized loss and the exposure, E, thus:

$$AAR = TIR = AAL/E = (f_1 * L_1 + f_2 * L_2 + \cdots + f_n * L_n)/E \tag{2}$$

Equations (1) and (2) can be cut off at a lower loss, the deductible, and at a higher loss, the maximum or probable maximum loss, PML, that is wished for any risk transfer scheme and for insurance and re-insurance purposes. Therefore the AAL is the minimum technical insurance rate needed to accumulate resources for paying for future losses in the buildings. Data used for equations (1) or (2) can be plotted either as frequency mass, cumulative or complementary functions for easy reading and decision making. A maximum loss criterion, choice of the PML, can be done executing a deterministic, scenario-based loss analyses, as in the studies for the District of North Vancouver, in British Columbia (Wagner, et. al., 2015) or the study of the effects of a major earthquake for south British Columbia and Ontario (Air, 2013); or selecting the loss corresponding to a given annual frequency of exceedance from a complementary function plot.

2.3. Commercial rates

Commercial insurance rates, CIR, include administrative costs and in practice are controlled by the insurance and re-insurance offer and demand, market conditions. Therefore, they can be higher or lower than the technical insurance rates, TIR (AAR). In the case that the CIR are less than the AAR, only a fraction of the risk is being covered. On the other hand, if the CIR, excluding administrative costs, are more than the AAR, an excess of money is being charged to the property owners. Note that for a given commercial rate, it is always possible to know what is the fraction of the risk that is being covered, in other words fixing a commercial rate and a deductible, it is possible to know what is the maximum probable loss that is being covered, an issue that has a special significance as it will be discussed later on.

For the Vancouver region, the earthquake commercial annual rates, CIR, for standard buildings and houses are currently in the range from 0.5 cents to 20 cents for every CA 100 of insured value, although most commonly between 8 cents to 20 cents for every CA 100, i.e. 0.8‰ to 2‰, or 0.8 dollars to 2 dollars per every 1000 CA dollars of insured value (Tablotney, 2015; MIR, 2015). These rates are usually for deductibles in the order of 10% of the insured value and excluding losses related to liquefaction. The insured value is taken as the replacement value of a property. The re-insurance rates include different schemes (proportional, non-proportional, etc), deductibles, maximum losses limits, depending on the specific needs of the insurance companies.

2.4. Individual and portfolio of buildings analyses

There are significant differences in determining the frequency of losses for individual buildings or for a set, portfolio, of properties.

The distribution of losses for individual buildings can be estimated, for example, but not exclusively, following the next simplified steps:

-Determine the seismic hazard curves that is the frequency of exceedance of ground motions and the corresponding annual probability density functions.

-The functions mentioned before can be then integrated directly with probabilistic loss functions expressed in terms of ground motions, e.g. spectral acceleration, or with loss functions, based on different response parameters like spectral displacement, using, for example, the capacity spectrum method.

-Integrate the annual probabilities of ground motions or of spectral displacements with a probabilistic loss function, a fragility curve, for the building, to obtain the annual distributions of losses. An earthquake by earthquake approach for estimating losses can also be used.

When an analyses of a portfolio is required, it is not possible to aggregate the individual distributions of losses because they are correlated, apart from the fact that the spatial sparseness of the buildings make compulsory the use of an earthquake-by-earthquake analysis. Approaches using Monte Carlo simulations are common to determining the full distributions of losses in this case.

It is worth highlighting that the methods, for estimating the distributions of losses for solitary buildings are far simpler than those used for a portfolio analysis, so the moving of engineering design towards risk based design is not as complex as it may appear at first glance.

3. Loss, Risk curves

A Risks and Hazards Earthquake Analyses, RHEA©, software that allows estimating the annual expected frequencies of earthquake losses was developed by the authors. The program can use any seismological model, type of soils, and different structural and use type of buildings. The age of design of the building is related to different Code vintages, Pre, low, moderate, high level. Structural types and design Code fix issues like yield and ultimate capacity, drift at which different levels of damage starts; while use of building are related to distributions of values between structural and non-structural components. The recent seismological model developed by the Geological Survey of Canada (Halchuck, et. al. 2014) was implemented in the program. Figures with preliminary results are included below, for illustration purposes

Figure 2 shows annual frequencies for 2 wooden buildings, less than 3 storeys, located in the city of Vancouver. The first one corresponding to a Pre-Code era (W-Pre-Code), and the second one to a High Code vintage (W-High-Code). Note that as it is expected the frequencies of losses are higher for the Pre-Code building. Figure 3 shows the cumulative frequencies of losses, i.e. frequencies of losing less than a given loss; and Figure 4 provides the complementary frequencies, i.e. frequencies of losing more than a specified loss for the two houses. Figure 4 is redrawn in Figure 5 using a log scale for the frequencies.

Naturally, it is possible to de-aggregate risk by seismic source. Figure 6 shows the individual effect of several seismic sources on the frequencies of exceeding losses for a wooden building, high code vintage, in the City of Vancouver. The figure highlights that earthquake risk for the building is dominated by the effects of the Vancouver Island Coastal Mountains, the Georgia Strait/Puget Sound (Deep) and the Puget Sound shallow seismic sources.

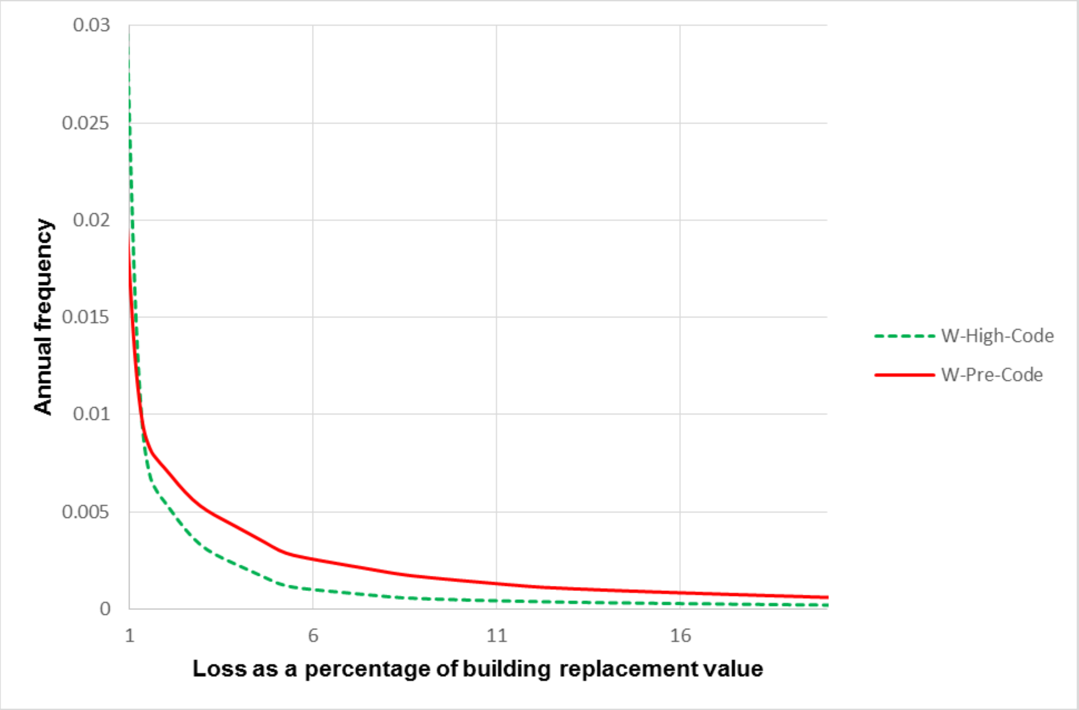

Fig. 2 – Annual frequencies of losses for 2 wooden buildings in the City of Vancouver.

Fig. 3 – Cumulative annual frequencies of losses for 2 wooden buildings in the City of Vancouver.

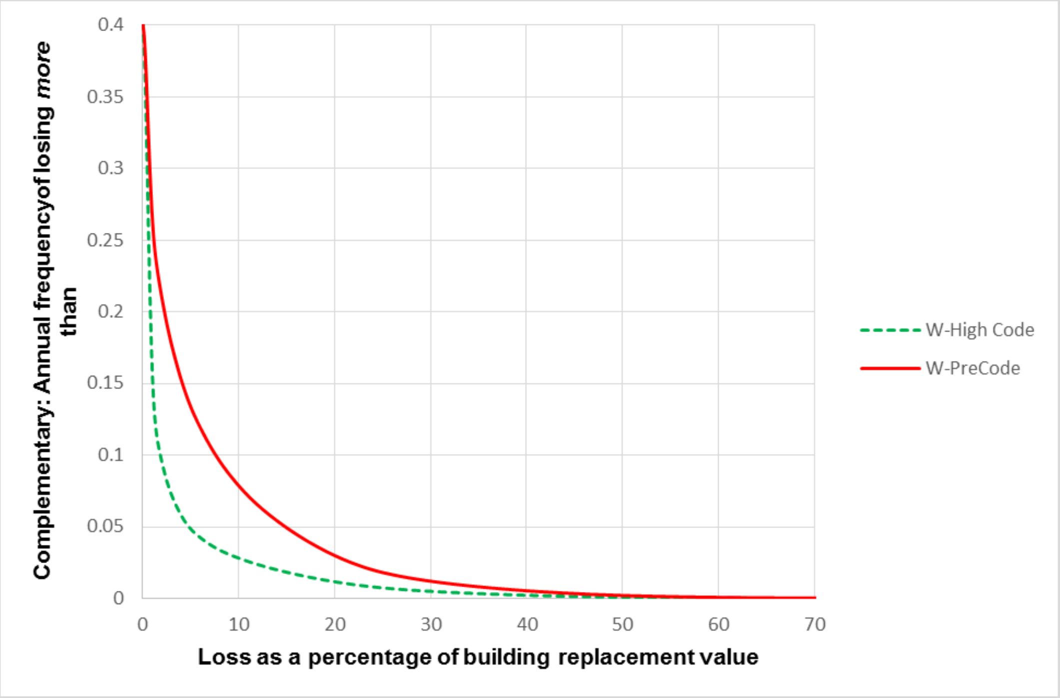

Fig. 4 – Complementary annual frequencies of losses for 2 wooden buildings in the City of Vancouver, i.e. annual frequencies of losing more than a specific loss.

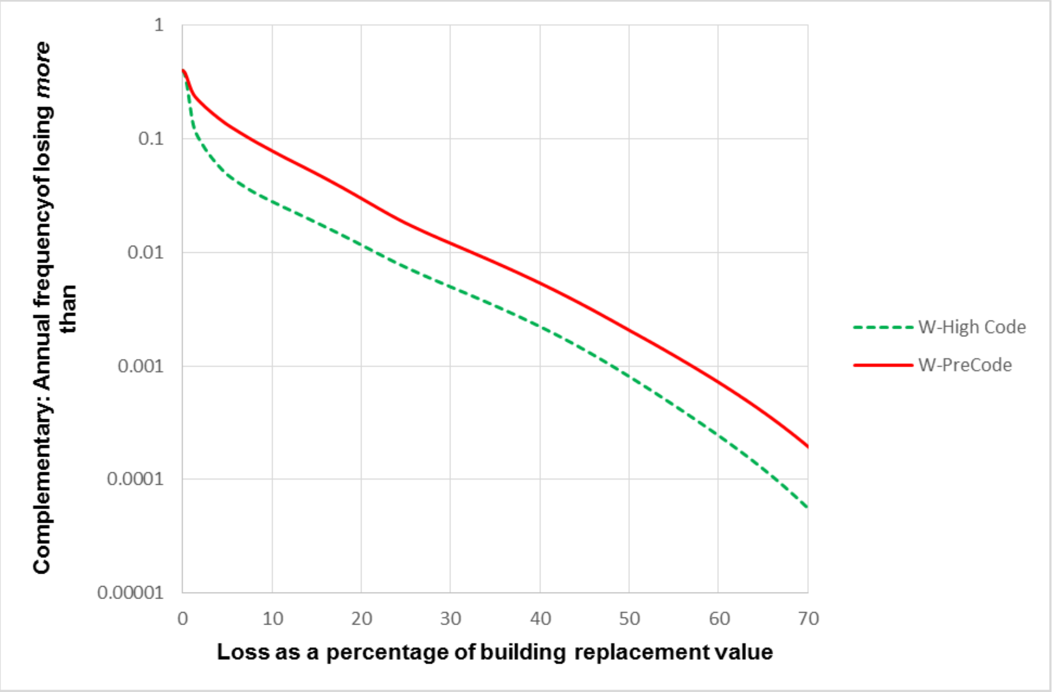

Fig. 5 – Complementary annual frequencies of losses for 2 wooden buildings in the City of Vancouver, i.e. annual frequencies of losing more than a specific loss. Semi-logarithm plot.

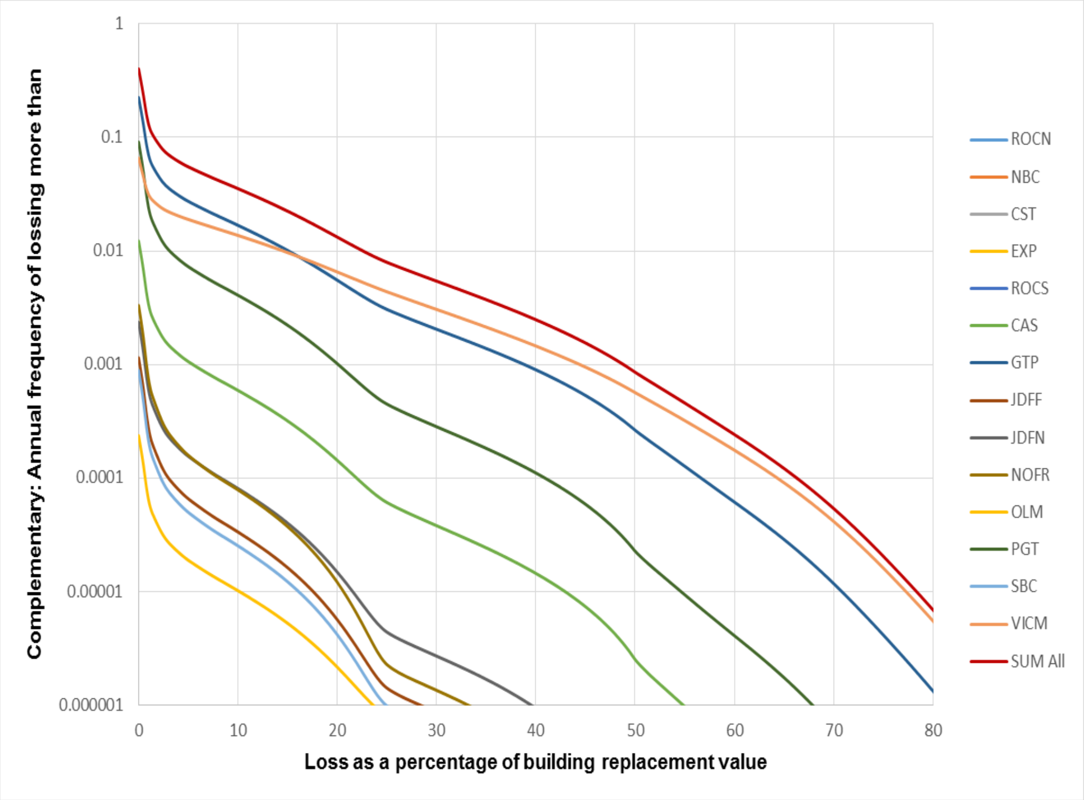

Fig. 6 – Deaggregation of seismic risk, i.e. contributions to annual frequencies of exceedance of losses for a wooden building in the City of Vancouver.

It is important highlight that although Figures 2 to 6 are expressed in term on monetary losses, they can easily be expressed in terms of social losses, injuries, and casualties or casualty rates, if decisions are planned to be taken using social criteria. For the rest of the document, we are going to use monetary losses.

4. Criteria to incorporate insurance rate in seismic design, performance objectives

Data provided by graphics like those ones shown in Figures 2 to 6 can be now used for developing criteria that can complement the seismic design of buildings.

An initial possibility is using a *maximum, fixed or uniform, AAR,* or *AAL, criterion*, considering the whole distribution of losses, i.e. zero deductible and a PML = 100%, i.e. using equations (1) or (2) without any cut offs. Clearly, in this case, there is no consideration of the commercial rates. To apply this criterion a reference standard, prototype building with high level of earthquake design characteristics, has to be selected. Our preliminary results using RHEA, show that the ratio between the whole average annual loss of Pre-Code vintage buildings, $AAR\text{-}PC$, and that corresponding to a Hig-Code design, $AAR\text{-}HC$, seems to be in the order of 2 for low rise wooden and concrete frame buildings. Therefore, a design criteria might state something similar to:

The average annualized ratio associated to earthquake losses of the building, for 0 deductible and a PML equal to 100%, must not exceed that one corresponding to the reference high level design building, at the same location.

A second criterion, might be fixing the loss corresponding to a specified annual frequency of exceedance, or its inverse, the period of return. If the loss corresponding to a period of return of 1500 years is in the order of 50% of the replacement value for a high level design code building, the design criterion could be:

Results of the risk analysis of the building must show that the loss corresponding to a period of return of 1,500 years do not exceed 50% of the replacement value.

A third possibility, a *current payable risk criterion*, involves commercial rates, and the maximum current payable rates. It was already mentioned that current commercial annual rates for the Vancouver region has values as high as 2‰ of the replacement value for 10% deductible. This means that during a 30 year interval, the normal mortgage amortization period in the region, a value of 2/1000*30 = 6/100 of the replacement cost can be collected to pay for losses. This value is reduced to about 5/100 if some administrative and profit costs are excluded. Keeping a deductible of 10% (at least initially as will be discussed below) the maximum loss that can be paid during the 30 year period at the 2‰ rate is 10+5= 15% of the replacement value. Note that if the actual loss after an earthquake is 15%, the owner is going to take 10/15*100=66% of the loss and the insurance company is going to pay 5/15*100=33% of the loss. Our preliminary results are showing that losses corresponding to a 30 year return period fluctuate, some can be higher (for older buildings) and others can be lower than 15% for modern high code design buildings. Losses higher than 15% cannot be paid, unless, an increase in the commercial rates is accepted by society. On the other hand, clearly, if the 30 year loss calculated from the risk analyses is less than 10% then the deductible set by the insurance companies must also be less than 10%, if they preserve a 2‰ rate, and/or the commercial rate has to be reduced. Note also, that if the commercial rate is reduced because market conditions, pressure is put on the structural design to reduce the expected loss. So, a design criterion that involves the participation of the insurance sector, could be:

The loss calculated from the risk analysis corresponding to a period of return of 30 years has to be shared in the same proportion between the insurance company and the building owner, and cannot exceed 15% of the replacement value of the building.

5. Conclusions

- Earthquake risks are increasing in British Columbia and in any populated region with some level of seismic hazard around the world.
- There is no connection between current design parameters of the codes and the new performance based procedures based in social and economic consequences and their probabilities. The language and parameters used in current Codes are completely useless for decision makers and social or economic risk management issues. It is not possible attempting financial mitigation of earthquake risks using the engineering design parameters provided by the methods available in existing Codes. The uncertainty due to the lack of objective measures of earthquake risk in present day Codes is threatening the security of both our social and economic systems.
- The present state of art of Performance based design incorporates the risk framework and have opened the door for new performance objectives that can use the building risk curves. Using results of a recent software developed by the authors for estimating losses and their frequencies/probabilities, RHEA, three examples of performance objectives are proposed here. They are: A maximum *AAL* criterion; the loss corresponding to a period of return; and the current payable risk criterion. The invitation for discussion and selection of useful performance objectives to be implemented in the new codes is therefore open.

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