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AN INTEGRATED METHODOLOGY FOR URBAN SEISMIC RESILIENCE PLANNING – CASE STUDY FOR SCHOOLS IN MANILA

Jack GUO[1], Kevin JESWANI[2], Constantin CHRISTOPOULOS[3]

ABSTRACT

This paper introduces an integrated platform for seismic resilience planning and decision-support that is scalable to different sizes of urban building portfolios. The platform is implemented into a computer tool for portfolio assessment. The proposed tool is capable of providing very rapid determination of higher resolution risk analytics and mitigation measures that enables owners and stakeholders of building portfolios to gain quantitative understand of their risk exposure in multi-dimensional risk metrics at include both financial loss and recovery time, at the project onset without engaging engineering consultants for detailed design. This paper first introduces the platform tool and the motivation for its development. Then it describes an application example where the proposed tool is used to assess the seismic risk and resilience of a large network of schools in Metro Manila. The results obtained from the application highlight the substantially richer details of the risk exposure inherent in building-specific analyses, which transfers to a portfolio of similar buildings. This study illustrates the feasibility of the proposed integrated tool for generating risk analytics and risk-mitigation options for decision-support of owners of large portfolio of building properties prone to earthquake risk.

Keywords: performance-based seismic risk assessment; REDi methodology; building portfolio risk

1. INTRODUCTION

With the improvement in computational capability, probabilistic earthquake risk assessment is becoming very feasible and more common at the building-specific level. Following the FEMA P-58 methodology (ATC 2012) or the USRC rating system (USRC 2015) engineers can now quantitatively evaluate the financial, safety and business impacts associated with damage in buildings due to earthquake hazard exposures, accounting for the different sources of uncertainties. These analytics can then be used by building owners as decision-support tools for risk management. However, for stakeholders, who own a relatively large portfolio of similar buildings, adopting the building-specific risk method to each individual building quickly becomes prohibitively expensive and time-consuming. Furthermore, portfolio owner may be more interested in addressing risk at a more holistic level that involves decisions variables that are not defined at the building-specific level. In this sense, drilling down to the building-specific details of risk is both not necessary and inefficient, particularly in the case where a few key building types that are representatively of the portfolio can be identified. On the other hand, while existing macroscopic risk approaches, such as HAZUS (FEMA 2013), may provide relatively quick assessments based on generic building-archetype-based fragility and vulnerability functions derived from analysis of single-degree-of-freedom (SDOF) systems, they are usually more relevant for very large building portfolios where the details of each building are not important as they will be washed out by the uncertainty in the large set of buildings. For portfolio sizes that are in the tens to the hundreds however, the macroscopic approach does not capture enough resolution to be able to

[1]Seismic Risk Lead, Kinetica, Toronto, Canada, j.guo@kineticadynamics.com
[2]Graduate Researcher, Department of Civil Engineering, University of Toronto, Toronto, Canada, kevin.jeswani@mail.utoronto.ca
[3]Professor, Department of Civil Engineering, University of Toronto, Toronto, Canada, c.christopoulos@utoronto.ca

make specific recommendations for risk mitigation.

Several past studies have attempted to address this problem by using a "hybrid" approach where more sophisticated dynamic models are used to capture the fragility and/or vulnerability functions of buildings in a portfolio. For instance, Goda and Yoshikawa (2012) used the SAWS model (Folz and Filiatrault 2001) for wood frame to investigate the insurance losses of building stock in British Columbia, Canada. A similar study has been performed by Ottonelli et al. (2015) for masonry structures. Recently, Lamego et al. (2017) analyzed an urban portfolio in Lisbon using fragility functions derived from direct nonlinear time-history analysis of several representative low, medium and high-rise building systems. More notably, recent studies have used the FEMA P-58 methodology for building-specific risk analysis to characterize vulnerability functions (Burton et al. 2015) and for direct nonlinear time-history based portfolio analysis (Zeng et al. 2015, Ottonelli et al. 2015). One drawback common to these previous studies is the lack of an explicit evaluation of risk as a multi-dimensional decision-variable. In particular, the recovery of the building stock and the benefits of mitigation effort is not examined. To address this issue, the current paper proposes a simple extension for building-specific seismic risk methods to a more general methodology for evaluating both financial losses and recovery times of a multi-building portfolio. The losses and recovery times are computed using the US Resilience Council (USRC 2015) method, which is based on the use of FEMA P154 Rapid Visual Screening (ATC 2015) for collapse evaluation, FEMA P-58 (FEMA 2013) for non-collapse losses and the REDi methodology (Almufti and Willford 2013) for re-occupancy, functional recovery and full recovery times. The methodology involves first selecting key representative building(s) in a portfolio, and simplifies the representation of individual buildings using a set of functions derived from building-specific analysis of the selected key buildings, which are analogous to the vulnerability functions in a macroscopic risk assessment. These new functions provide higher resolution descriptions of the probabilistic distributions of different decision-variables, including financial losses and various recovery time indices, conditioned on an input seismic intensity measure, which are in turn generated either from site-specific hazard curves, or from stochastic events described by appropriate ground motion prediction equations (GMPE). With the help of these functions, a large portfolio of buildings can be analyzed with much less computational effort, and opens the possibility for systematically evaluating the impacts of mitigation measures in the context of minimizing portfolio risk.

The proposed methodology and its inter-relations with other risk assessment tasks are first introduced and described in this paper. Then, the probabilistic formulations that extend the building-specific method to one compatible with multi-building portfolio is presented. Using this methodology, an application example for the preliminary portfolio risk assessment of spatially distributed high school buildings in metro Manila is then presented to illustrate the proposed method and to highlight its advantage relative to the more common procedure that uses generic fragility and vulnerability functions.

2. PROPOSED PORTFOLIO RISK METHODOLOGY

2.1 Methodology Overview

Building-specific risk assessment following the FEMA P-58 methodology uses seismic intensity measure (IM) to generate engineering demand parameters (EDP), which are in turn used to compute damage states (DS), and subsequently consequences or decision-variables (DV), which are reviewed by the end-user to make informed decisions. The generation of EDPs from a given IM is arguably the most time-consuming and difficult task to perform, and it is justified because it better relates to the damage and thus loss than if a simple IM is used. However, unless buildings within a portfolio are extremely diverse, there is often little reason to model each individual building in a portfolio using the building-specific approach since it is unlikely that the losses are sensitive to small changes in EDP (assuming that collapse is not imminent). In the case of building portfolios comprised of similar structures (for instance fire halls, police stations, utility service stations, schools), the use of a single or a few representative buildings to model the loss of a much larger building portfolio can be a good compromise between computational effort and accuracy (Note: the term "loss" is used here to denote negative consequences resulting from earthquakes and can incorporate financial losses, casualty and downtime indices, which form a multi-dimensional measure for risk). This hybrid approach takes advantage of the higher resolution of loss data offered by the building-specific analysis without investing excessively in computational resource since the building-specific analysis is performed only for a small fraction of the buildings, and can be completely separated from the rest of the portfolio analysis. This type of analysis is expected to be very efficient for assessing the risk of portfolios made from similar structures.

Figure 1 shows a diagram that describes the key steps in the proposed methodology for portfolio seismic risk analysis. The proposed procedure starts with the classification and identification of key representative buildings within the portfolio that are used to derive loss distributions. For each key building identified, a building-specific loss analysis is performed over an entire range of possible seismic intensity to derive the financial loss and the REDi recovery time distributions (i.e. loss distributions). This step involves performing nonlinear time-history analysis to derive the building EDPs for each seismic intensity level, calculating losses from the thus derived EDPs and constructing the loss distribution curves conditioned on the current seismic intensity. The improvements of the proposed method relate to the generalization of the loss distributions to capture consequences other than financial loss, and in the method for constructing the loss distribution curves, which are described in more detail in the next section. The resulting loss distributions contain all the necessary information for portfolio loss simulation and are assigned to each building in the portfolio for loss analysis.

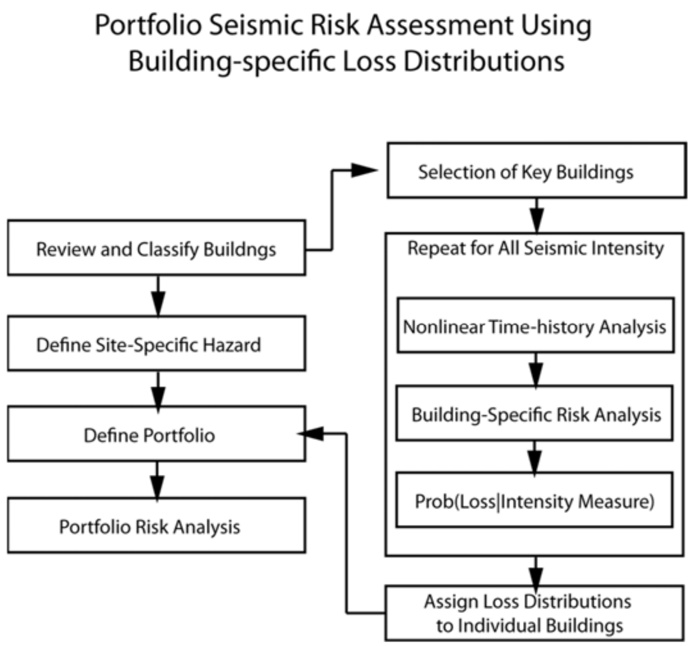

Figure 1. Illustration of portfolio analysis using building-specific loss distributions from key buildings

Portfolio risk analysis is performed using Monte Carlos Simulation where the following is evaluated repeatedly for a fixed number of realizations:

$$L^{[k]}_{i,j} = F^{-1}(p^{[k]}_{i,j} \mid IM = im_{i,j})$$

where $L^{[k]}$ is the k^{th} consequence in the loss vector for a specific site, where k = financial loss, REDi re-occupancy time, functional recovery time, and full recovery time. The term $L^{[k]}_{i,j}$ denotes the k^{th} consequence for the i^{th} site in the j^{th} realization. The function F is the conditional probability distribution for losses given the seismic input intensity, which are derived from the building-specific loss analysis of corresponding key buildings in the portfolio using the multiple stripes method (Jalayer and Cornell 2009) where the loss distributions are computed at discretized intensity levels. The inverse of the conditional loss distribution F^{-1} thus maps a given probability of non-exceedance, $p^{[k]}_{i,j}$ and an input intensity, $im_{i,j}$ to the loss value. During each realization, an intensity measure is generated for each building site in the portfolio in accordance to the hazard model. For time-based analysis, the seismic intensities at a given analysis time interval can be determined from the information on the hazard curve, which maps the spectral acceleration values to a mean annual frequency of exceedance (MAFE). For scenario-based analysis, stochastic events can be generated using appropriate GMPEs and correlation models. Although the selection of appropriate GMPE and correlation models is not the focus of this study, it is extremely important to the final results as demonstrated in numerous studies in the past (see for instance: Bazzurro and Baker 2007, Goda and Hong 2009, Sokolov and Wenzel 2011). Once the intensity measure is determined at each site, a random sampling of probability will uniquely determine the loss.

Figure 2a shows a depiction of the loss function F generated from the proposed building-specific analysis on key buildings by stitching together conditional loss distributions at different intensities. The resulting "loss surface" relates the value of building losses (financial or otherwise) to an input intensity and a probability of non-exceedance. During one realization in the portfolio analysis, an input intensity measure (e.g. spectral acceleration at the building fundamental period) is sampled for each site, and a probability of non-exceedance is sampled randomly. These two sampled values define the realization loss completely, thus allowing the portfolio analysis to map intensity measures directly to losses, which are the ultimate decision variables without computing the intermediate EDPs and damaged states. Rather than using one of commonly used probability distributions for the loss (i.e. lognormal distribution, beta distribution), the proposed method for constructing these loss surfaces is to discretize the empirically generated loss distributions by their decile (0^{th}, 10^{th}, 20^{th}, …, 90^{th} and 100^{th} percentile), and construct a linear interpolant function in between. This is important because many loss distributions have non-smooth features caused by either limiting value of losses or probability of having zero loss. Figure 2b shows the discretization of loss distributions into their respective deciles, from which linear interpolant functions are constructed for risk analysis.

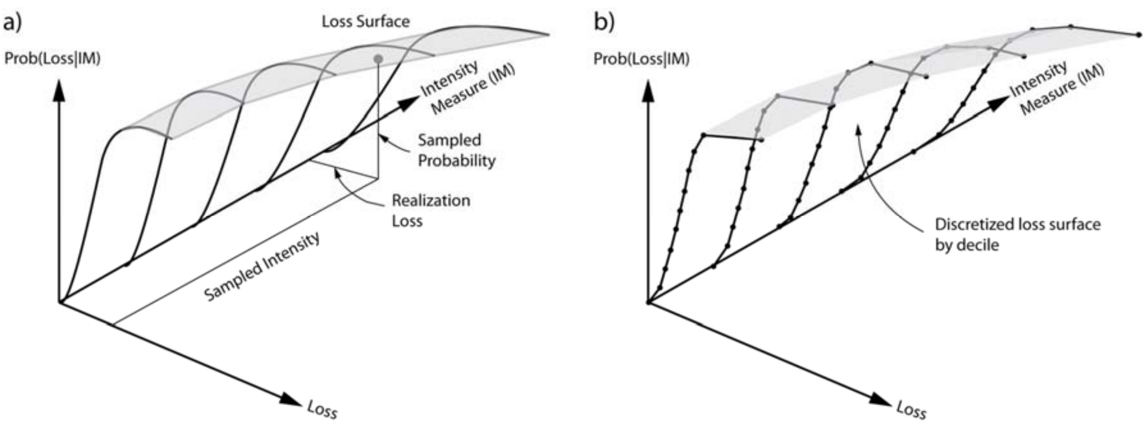

Figure 2. Portfolio analysis using loss distributions

2.2 Generation of Loss Distributions

As mentioned previously, the loss distributions for key buildings considered in this study include financial losses and recovery times generated using the FEMA P-58 and REDi (Almufti and Willfod 2013) methods. Collapse modelling is performed using the USRC approach (USRC 2015), which is based on converting the FEMA P154 rapid visual screening score to a collapse probability. Given an input seismic intensity, if collapse occurs, the replacement costs and time are assigned as the financial loss and recovery times. If collapse does not occur, the FEMA P-58 and REDi procedures are followed in order to determine the financial losses and the recovery times. For completeness' sake, the process is illustrated in Figure 3.

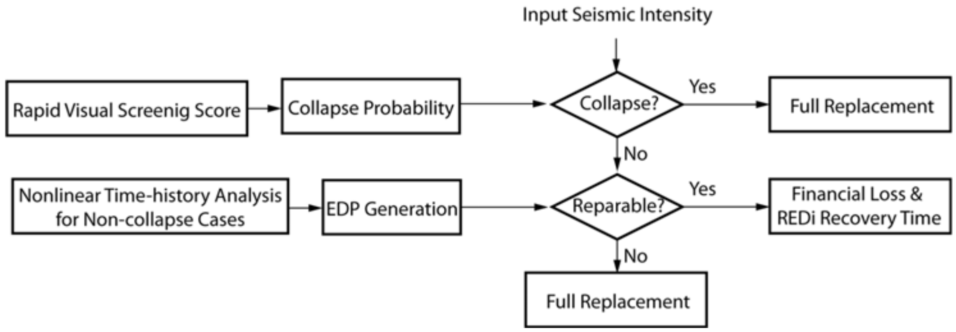

Figure 3. Process for generating building-specific loss distributions

The REDi recovery times are separated into re-occupancy, functional recovery and full recovery, and they are determined by scheduling post-earthquake events according to the REDi logical sequence that accounts for pre-repair tasks called impedance factors, and the actual repair tasks. The durations of each impedance factor and repair task are determined by the extent of damage in each of the building's components, as well as the allowable labour resource that can be allocated for each repair trade and for each building site. In practice the optimum recovery time is not unique since repair tasks that are not on the critical path can vary without affecting the total recovery time. In the current implementation a gradient decent algorithm is used on the REDi recovery time to determine the optimal allocation of labour forces across different repair trades subjected to the worker limit constraints.

It is important to recognize that depending on the end goal of the portfolio owner, different recovery time may be of interest. For schools and community centers that are designated as emergency shelters for example, the re-occupancy time would be the appropriate quantity of interest. For emergency response buildings such as police stations and fire halls on the other hand, functional recovery is likely the quantity of interest. Although for a given realization in a building-specific analysis full recovery always follows functional recovery which follows re-occupancy, the different recovery times determined in each realization from sampling the resulting loss distributions in a portfolio analysis are independent and should not be considered to come from a single event.

2.3 Portfolio Analysis

Once the loss distributions are generated for the key buildings, they are assigned to each building in the portfolio being considered based on the level of similarity to the key buildings. This step requires some engineering judgement and is based on the similarity of the fundamental period, structural system types and building area, usage type and whether there are existing structural deficiencies. The assigned loss distributions are then called in each realization to produce a loss value (financial or otherwise) using Monte Carlos sampling of the seismic intensity. In this step, different building-specific loss quantities of interest are determined independently. Aside from the financial loss and recovery time, loss distributions for other building-specific performance metrics derived from these losses quantities can also be constructed.

3. SEISMIC RISK ASSESSMENT OF PUBLIC SCHOOL BUILDING STOCK IN MANILA

3.1 Introduction

As a sample application of the proposed methodology, a very preliminary seismic risk assessment of school building stock in Metro Manila with an approximate enrollment of 65,000 students (a portfolio with 72 schools buildings near the Marikina Valley Fault with randomized location) is performed. This type of analyses can be used to provide key insight on the seismic resilience of critical government infrastructure in the scenario of an earthquake in the Marikina West Valley Fault, which is expected to produce strong earthquakes near the city. In particular, the reoccupancy and functional recovery times for the school portfolio is of interest as these are measures of the availability of post-disaster shelter space, as well as the number of students who will not be able to attend school in the aftermath of an earthquake. An infrastructure audit has been performed by the Metro Manila authorities, which enables the classification and identification of the most common buildings in the portfolio. This example application describes a very preliminary portfolio analysis based on one key building that is representative of a large portion of the portfolio. For simplicity, the building-specific analysis considers 3 intensities (service level, design level and maximum considered level shaking) to discretize the hazard curve. Although most building-specific analysis requires finer discretization of intensity levels, for the purpose of illustrating the proposed method, using 3 levels is deemed sufficient. Figure 4 shows a map of the area with the Marikina West Valley Fault, as well as the assumed epicenter of this analysis based on a recent study by Allen et al. (2014).

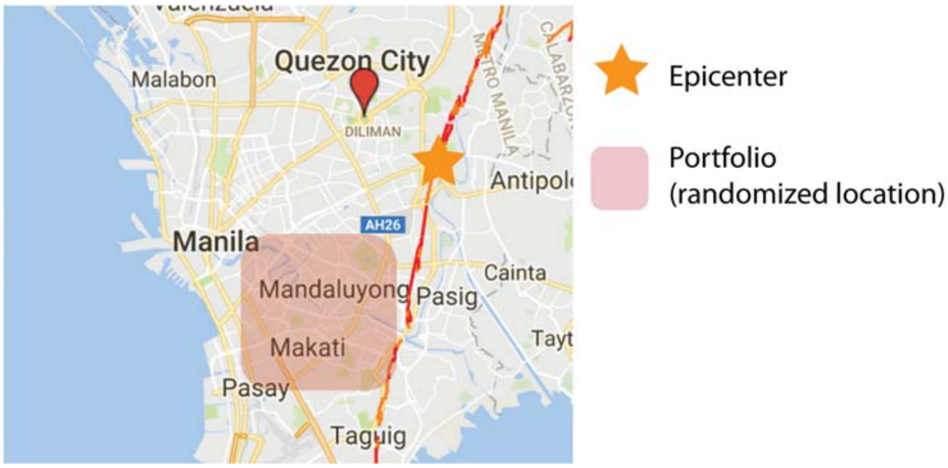

Figure 4. Metro Manila map showing Marikina Valley Fault with epicenter and portfolio location

The key building being examined is a typical reinforced concrete moment frame (RC-MRF) with concrete hollow block (CHB) infill in Manila. This type of structural system represents approximately 58% of the portfolio considered (for simplicity however, it is assumed that all buildings in the portfolio can be described by the selected key building). This is a common low- and mid-rise structural system in the Philippines, where CHB infills are considered non-structural elements for interior and exterior walls during their design.

3.2 Development of Nonlinear Model for the Key Building

In the absence of as-built structural drawings during this stage of the project, the structure was redesigned as a ductile MRF system using architectural drawings, as well as other available supplemental reports (Kubo et al. 2004 and Miyamoto et al. 2014) using the NSCP 1986. Figure 4 shows the plan and elevation views obtained from the architectural drawings of the selected key building, as well as the numerical model used of dynamic analysis.

The building footprint measures 17.5m by 22m (in the x- and y-directions, respectively) and 17.5m from the assumed top of footing to the centreline of the roof beams. Figure 4 also illustrates the 3D non-linear structural model developed in SeismoStruct (Seismosoft 2013). The RC compressive strength f_c', was assumed to be 21 MPa and a rebar yield strength is assumed to be 276 MPa. Column dimensions are 450 mm x 450 mm and are reinforced with longitudinal bars ranging from 8- to 20-20 mm, with 10 mm stirrups spaced at 75 mm. Girder dimensions are 300 mm wide by 600 mm deep for floors 1 through 4 and 300 mm wide by 400 mm deep at the roof level. All girders are reinforced with 3- to 5-28 mm bottom longitudinal bars and 3- to 6-28 mm top bars, with stirrups spaced at 100 mm. CHB infills are not present in certain bays on the ground floor (which is typically used for assembly purposes) and have a staggered presence throughout the rest of the building. Dead loads were applied to the girders as additional masses. Base nodes were fully fixed in all directions. Rigid moment connections were used for all joints. Rigid diaphragms were incorporated into the model by slaving all nodes per level to a master node close to the center of mass. Rayleigh damping is used with 5% for the 1st (T_1 = 0.427s) and 3rd (T_3 = 0.090s) modes.

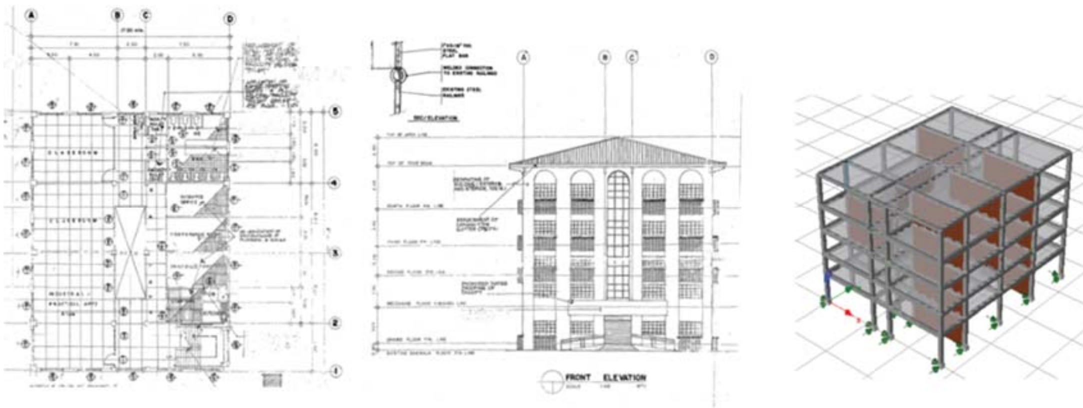

Figure 5. Typical school architectural drawing and the 3D SeismoStruct model

The uniaxial nonlinear constant confinement model of Mander et al. (1988) was chosen to represent the frame elements, which considers the effects of confinement by provided transverse reinforcement. The bilinear model was used for all steel reinforcements. The RC-MRF was modelled using inelastic force-based plastic hinge frame elements, which use a distributed inelasticity displacement and force-based formulation and concentrates the inelasticity within a fixed length of the element. The plastic hinge lengths (l_p) for each frame element were taken as the average of $l_p = 0.5h$ and $l_p = 0.08L + 6d_b$. Typical interior non-load bearing 102mm (4in.) thick CHB infill panels were modelled using SeismoStruct's built-in six-strut inelastic infill element (Crisafulli 1997), which consists of masonry struts governing the wall shear behaviour, as well as a nonlinear shear spring for mortar failure. A masonry compressive stress (f'_m), of 2x2.4mPa was used, based on previous observations of significantly higher CHB strength than the reported f'_m. (Mendoza et al. 2011). The modulus of elasticity of the CHB was defined as $750f'_m$. The proportion of total infill element stiffness assigned to shear spring (γ_s) was 0.2. The remaining values defining the hysteretic axial and shear models were left as default (including the shear bond strength of the infill panel being taken as a typical 300kPa and friction coefficient (μ), being 0.7), due to lack of specific reference to local material testing.

3.3 Collapse

Prior to developing the loss distributions, the probability of collapse for the chosen key building was determined based on FEMA P154 (ATC 2015) RVS level 2 score obtained from the infrastructure audit. The score for this building is determined with the P154 level 2 form for "Very High" seismicity, under structural system C3 (RC frame with masonry infill). Due to the existence of a soft/weak first storey, the final score S = 0.4, which can be converted into a collapse fragility using the USRC method (USRC 2015). The resulting lognormal collapse fragility has a median S_a value of 2.51g, with a dispersion parameter of 0.7. If collapse occurs, the total financial loss and downtime are set equal to the replacement value and time of the building. In this example, the building replacement cost was assumed to be \$6.5M USD and 730 days, respectively.

3.4 Building-specific Loss Distributions

The non-collapse losses were derived following the FEMA P-58 and REDi methodologies using nonlinear time-history analysis (NLTHA). The guidelines set out in ASCE 7-10 (ASCE 2013) were followed for ground motion (GM) selection for use in NLTHA using 11 ground motions. According to Metro Manila Earthquake Impact Reduction Study (JICA 2004), the most damaging earthquake potentially produced by the WVFS has $M_w = 7.2$ and the most probable is $M_w = 6.5$. The PEER NGA database was used to search for 9 ground motions within the following specifications: Mw of 6 to 7.2, R_{rup} of 0 to 25 km, V_{s30} of 180 to 360 m/s. In addition, 2 subduction megathrust earthquakes (Sumatra, 2007 and Iquique, 2014) were included in the ground motion suite (and scaled appropriately) to represent earthquakes from the Manila Trench subduction zone, based on Koo et. al (2009), Wong et al. (2014), and JICA (2004). A weight function was applied around 0.2 to 1.5 times the structures fundamental period of 0.427 s. Additional scaling factors were applied until the mean of the 11 records were above the PSHA determined Target Response Spectrum of the Philippine Earthquake Model (PHIVOLCS, 2018) (10% probability of exceedance in 50 years), between the range in investigation, for the design basis earthquake (DBE). The maximum considered earthquake (MCE, 2475-year) and service level earthquake (SLE, 72-year) were taken as 1.5 and 0.5 times the DBE scale factor, respectively, based on the study from Koo et. al (2009). The resulting spectral accelerations corresponding to the SLE, DBE and MCE intensities are 0.387g, 0.773g, and 1.160g for the *x*-direction and 0.345g, 0.690g, and 1.035g for the *y*-direction, respectively. Figure 7 shows the scaled spectra, the average scaled spectrum and the target design spectrum used.

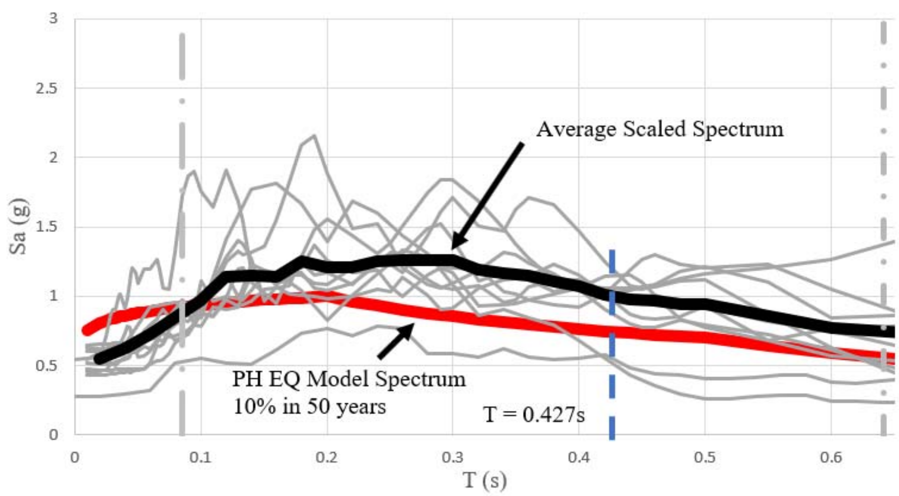

Figure 7. Scaled acceleration spectrum

A list of damageable contents in the building were generated based on the structural elements in the nonlinear dynamic model and the FEMA P-58 normative quantity tool. The collapse fragility, and the non-collapse EDPs obtained from NLTHA at each of the SLE, DBE and MCE intensity level were used to compute the financial and recovery time consequences of building using an in-house computer software, which performs both P-58 loss and REDi recovery time calculations. The resulting financial loss, re-occupancy time and function recovery time distributions at the three intensity levels are presented in Figure 8. It can be seen that the median losses, reoccupancy and functional recovery time are much larger for the MCE level than they are for the lower level of earthquakes. Several assumptions made in generating these loss distributions are noted. Firstly, the financial losses in the building-specific analysis are likely to be overestimated since the cost figures are based on North America repair costs. Experience from local engineers and cost estimators indicates that the labour costs in the Philippines can be less than half of the costs in North America. A similar argument can be made regarding the REDi recovery times since some elements in the repair schedule are determined based largely on North American practice (e.g. design and permit, worker limits…etc.). Getting accurate costs and time estimates from the FEMA P-58 and the REDi methods require a recalibration of the component costs time which is beyond the scope of this study. Hence, for the purpose of illustrating the proposed method, these quantities are used as they are. Note also in the building-specific risk assessment, when the total repair cost exceeds the replacement cost threshold, a replacement event is assumed to happen. This causes the loss and recovery times to be set equal to the replacement costs and time. This is manifested in the cutoff cost and time at \$6.5M and at 730 days. These features are not well modelled by smooth probability distribution curves and is the primary motivation for encoding the loss distributions as linear interpolant functions based on the decile values. In this example, the criteria for replacement is based only on the financial cost, but not the recovery time. In reality, the decision to replace a structure after earthquake damage is a more complex process and the current triggering rule is meant only for illustration purposes and is by not intend to model the actual decision-making process for this problem.

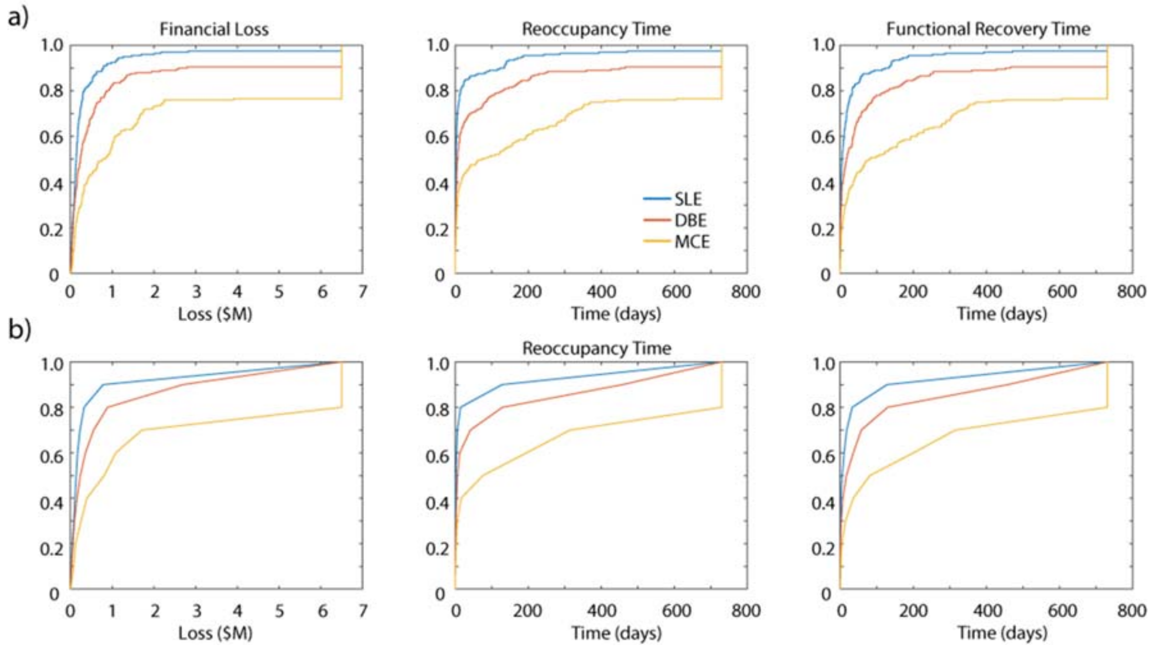

Figure 8. Distributions for financial loss, reoccupancy time and functional recovery time: a) building-specific data from P-58 and REDi analysis b) linear interpolation curves based on deciles.

3.4 Event Generation and Portfolio Loss Results

For this example a scenario analysis for a moment magnitude 7.2 event was carried out using the linear interpolant loss distributions obtained from the building-specific analysis. The epicenter is as indicated in Figure 4, and the ground motion intensity measures at each site were generated using an appropriate GMPE for the region. Based on the previous studies by Koo et al. (2009) and Allen et al. (2009), the Boore & Atkinson (2008) model (BA08) is identified as an appropriate GMPE for crustal events in the region, and is thus chosen for this study. In order to use BA08 to generate the median horizontal ground motion, a V30 velocity of 360 km/s is assumed for all sites (soil). For this analysis, it is assumed that all ground motion variability is contributed by the intra-event residual, and the spatial correlation relationship by Loth and Baker (2011) was assumed. This model was derived based on both Californian and Taiwanese records, and are deemed to be reasonable for the current application. In general, if spatial correlation data is not available, it is advisable to perform bounded analyses based on zero spatial correlation and perfect correlation.

Each intensity value at a given site is map to a loss value using the loss distributions. This analysis is repeated for each site in the portfolio, and for 1000 realizations to obtain the distribution of portfolio financial losses, the maximum building recovery time and the amount of student who lost access to their schools in terms of student-days. This last quantity was computed by multiplying the current enrollment for each school with the functional recovery time for each realization. The portfolio analysis took 25-30 seconds on an Intel i7 personal computer and the results of the analysis are summarized in Figure 9. Figure 9 shows that the median financial loss, median 90% reoccupancy time, median 90% functional recovery time, and median school disruption (defined as the total number of lost student capacity) are $59.0 million, 59 days, 441 days and 6.4 million student-days, respectively. Note that the 90% recovery times (90% of buildings achieve recovery) within the portfolio are used because the maximum recovery times in the portfolio may be much larger than the rest of the portfolio and are hence not good indicators of the overall portfolio recovery. The median and 90th percentile spectral acceleration experienced by the buildings are 0.55g and 1.12g respectively. Within the portfolio, in most cases buildings suffered damage dominated by the non-structural contents except for the buildings with locations closer to the epicenter where the larger spectral accelerations caused severe structural damage due to the soft-storey mechanism being activated at the ground floor where CHB infills are removed for atrium space. Figure 9 shows that as far as the portfolio is concerned, reoccupancy takes place much faster than functional recovery. The difference between functional recovery and reoccupancy is the repair of non-structural element that are crucial to the operability of the school buildings. This includes acceleration sensitive contents such as air conditioning systems, lighting and electrical systems. Damage to these elements are substantial since buildings with stiff CHB infills generally lead to larger floor accelerations.

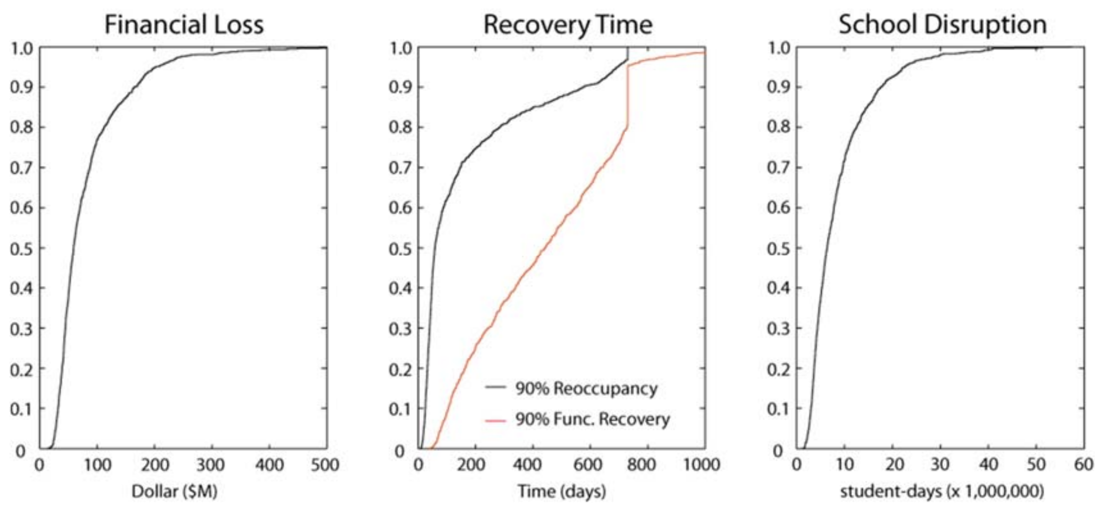

Figure 9. Portfolio results for scenario analysis of a M_w 7.2 earthquake in the West Valley Fault

Furthermore, given approximately 65,000 students are enrolled in these schools, the median disruption will amount to 98 days for each student on average, just more than 3 months. This can be pose a challenging situation for local school boards as new facilities need to be arranged for students to go back to schools. Further, the analysis can be drilled down to the individual realization level to identify which schools are the main contributors of school disruption. However, since the location of the schools in this assessment are randomized, this type of detail analysis is not performed.

4. CONCLUSIONS

An integrated methodology for seismic risk and performance assessment of multi-building portfolios that makes use of building-specific risk and downtime assessment methodology is presented. The proposed methodology extents the building-specific vulnerability functions to the more general loss distribution functions which captures financial losses and recovery times as determined by the REDi methodology. The method uses a decile based linear interpolant function to represent building-specific loss distributions that can be used to assess portfolio losses in a very rapid manner. The proposed methodology is illustrated with a sample school portfolio located in Metro Manila subjected to an earthquake from the nearby West Marikina Valley Fault. The result demonstrates the feasibility of proposed method for providing very rapid portfolio analyses that contains enough detail to determine specific performance metrics such as recovery times and functional disruptions. The illustrative example presented herein is very simplified, and preliminary since it does not account for the regional differences between repair costs and time and considers only a single scenario generated from a GMPE without accounting for regional effects of the mean and covariance of the ground motions. A much more in-depth analysis that addresses all of these elements is currently being carried out.

5. ACKNOWLEDGMENTS

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