# Simulated virtual portfolio for masonry buildings

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ABSTRACT: Assessment of damage costs due to an earthquake currently lacks the level of detail that is required for realistic pricing of individual insurance risks. Sophisticated numerical tools, which are widely used to assess structural behavior in great detail (like FEM), have been developed to a level where they may be used with confidence in seismic risk assessment and as such, enable the insurance industry to perform more realistic assessments.

In order to produce a virtual damage database, the "Simulated Building Portfolio"-Tool (SBP-Tool) was developed at the University of Kassel in cooperation with Munich Re. For using this tool several input parameters are needed in order to simulate a whole portfolio consisting of 3-D Finite Element models.

Thus validated virtual portfolios can be created now in regions with similar masonry buildings in order to assess damage costs where no or little event data are available.

## 1 INTRODUCTION

The assessment of damage losses due to an earthquake is an important issue for the insurance and reinsurance industry, but currently lacks the level of detail that is required for realistic pricing of individual risks.

Once a again, recent earthquakes that stroke Chile (Maule,Mw 8.8, February 6, 2010), New Zealand (Darfield, Mw 7.0, September 3, 2010 and Lyttelton, Mw 6.1, February 21, 2011) and Japan (Honshu, Mw 9.0, March 11, 2011) in the last three years proved the strategic importance of this kind of industry and renewed the crucial question of how to develop a resilient concept for society.

Any further advancement in that respect is strictly related to the capabilities of creating reliable models to predict seismic risk. This process implies a better understanding of the hazard, of the vulnerability and of the exposure that is involved.

Even if important on-going projects, like the Global Earthquake Model (GEM), are aiming at sharing and improving our knowledge, the "state-of-the-art" of the empirical data-set regarding earthquake's economic losses presents a severe non-uniformity. The worldwide information available is extremely different from both the quality and the geographical points of view.

Since earthquakes are rare events, the situation will not likely change significantly in the foreseeable future. It is therefore necessary to further investigate the development of innovative concepts based on consolidated numerical simulation techniques.

## 2 A NEED FOR COMBINING SOPHISTICATED SEISMOLOGICAL AND STRUCTURAL MODELS IN RISK SIMULATION

Guidotti (2012) shows how to describe a spatial variability of strong-ground motions through large-scale 3D simulations of wave propagation in near-surface soils. He developed complex 3D FE-models for a region of 1 km x 1 km and a depth of 50 m. More than 1.000.000 Finite Elements are typically required to simulated the wave propagation in a particular soil system.

Using these complex soil models, Guidotti assessed the response of buildings due to the simulated wave propagation by modeling them as rigid bodies (Fig. 1). This neglects the dynamic characteristics and the non-linear structural behavior of buildings despite being the controlling factors for the response of buildings under seismic actions. Furthermore, the seismic damage to a particular building cannot be estimated with such over-simplified models; a combination of such detailed wave propagation models with sophisticated structural models for the buildings in question is required if reliable data for seismic risk analysis is to be provided.

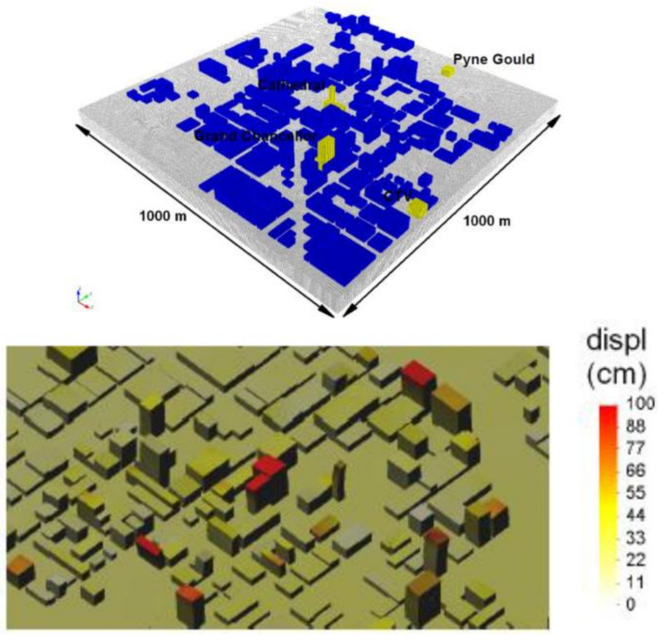


Figure 1. Top: Sophisticated 3D FE model of sub-soil with rigid blocks on top representing buildings in Christchurch. Down: A snapshot of the simulated displacement of the rigid block buildings. Guidotti (2012)

## 3 THE SBP-TOOL FOR GENERATING A VIRTUAL PORTFOLIO

To create this kind of building models, the so-called "Simulated Building Portfolio-Tool" (SBP-Tool) was developed at the University of Kassel in cooperation with the Munich Re, Mühlhausen (2010, 2011a, 2011b, 2012a). It provides a virtual portfolio of realistic buildings by using a set of global building criteria provided by the user in a configuration file. A statistical process automatically generates each individual building for the portfolio using the given range for each criterion.

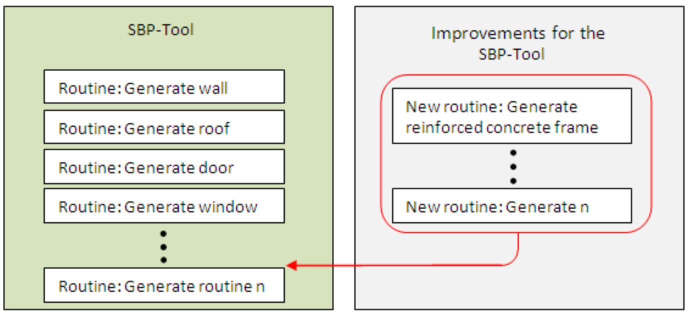


Figure 2. Import new routines to generic SBP-Tool, Mühlhausen (2012b)

The program is written in ISO C99 and features a modular design (Fig. 2). This allows for easy adaptation to different structures (steel frames, rc-frames with masonry infill, etc.) and inclusion of additional building features, like stairs or penthouses. Currently, the SBP-Tool is used to generate 3D linear FE-models of masonry buildings (Fig 3).

Using the configuration file, the SBP-Tool creates two ASCII files. The first contains the geometric and material data necessary for a FE-software to create a complex numerical model. It contains all the information regarding the nodes, elements, restraints and constraints, material properties for the roof, outer and inner walls, and the degrees of freedom (DOFs) subjected to loads. The second ASCII file contains the commands required for assembling the stiffness and mass matrices in the FE Software Slang (2004).

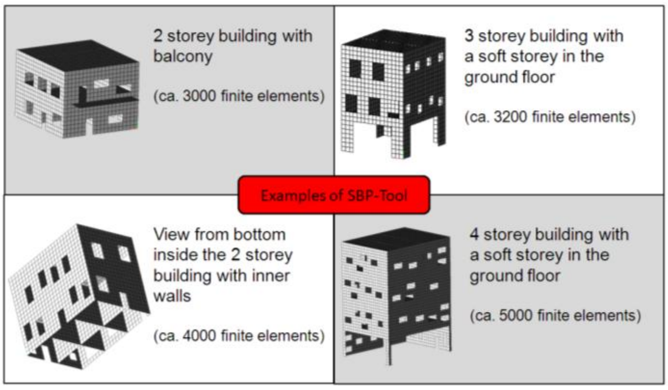


Figure 3. 3D linear FE-models for masonry buildings created by the SBP-Tool, Mühlhausen (2012b)

Whereas the first file does not depend on any particular FE-software, the second one must be adapted to its specific commands. This allows the use of other FE-software (Ansys, Open Quake etc.) without interfering with the initial generation process of the buildings.

SLang imports the ASCII files and, by executing the commands, it creates the mass and stiffness matrices. They are exported as two additional output files. Furthermore, Slang creates a file with all the information associated with each DOF. Thus, a set of 4 files is created for each building generated containing all the necessary information to perform a dynamic in particular a time history analysis.

In general (e.g. non-linear structures) around 500 power spectra are required to determine the standard deviation of a local variable with an accuracy of greater than 99 % according to the central limit theorem.

That means for a given portfolio like the one in figure 4 with 65 buildings and approximately 1.700.000 DOFs, 8.500.000 time histories analyses are required. To compute 8.500.000 time histories in a short period of time, the use of an efficient algorithm in combination with parallel computing (see chapter 4) is necessary.

In the case of linear structures, the use of power spectra provides an efficient way to calculate the required statistical values of local variables, which can be obtained by multiplying the transfer function of the local variable with the power spectrum of the input process (ground motion).

This transfer function describes the relationship between the output, a local variable (e.g. stresses), and a normalized input, the loading (e.g. excitation at the foundation – earthquakes). They are a property of an individual structure, and they can be determined without the knowledge of the loading event. Only the location where the load is applied must be known. For linear models, these functions are constant over time and therefore, they only have to be computed once.

They can be obtained by evaluating a single time history.

## 4 THE PORTFOLIO SIMULATION

To perform the time history analysis with the required efficiency and speed a parallel implementation of Dorka's substructure algorithm Roik (1989), Dorka (1991, 1998, 2002), Bayer (2005) and Dorka (2006, 2007) is needed. This algorithm is a discrete formulation of the dynamic equilibrium equation (1):

$$M\frac{d^2u}{dt}+C\frac{du}{dt}+Ku=p(t)+f_r+f_s \qquad (1)$$

Its integration constants $\gamma$ and $\beta$ are variables. With $\gamma = 0.5$ and $\beta = 0.25$, it becomes the well-known Newmark scheme. It also accommodates experimental and non-linear numerical restoring forces $f_r+f_s$ through a parallel sub-stepping process within each time step, thus avoiding time-consuming matrix inversions and iterations. Therefore, this algorithm can take advantage of multi-core and multi-processor computers using parallel libraries and other optimisations, resulting in solving 10000 DOFs in 43,94 ms per time step on a regular laptop computer Obón Santacana (2011a, 2011b, 2012). In other words: the simulation of one of the buildings in Figure 3 with 10000 to 12000 DOFs subjected to an earthquake of 40 seconds (4000 time steps) needs app. 3 minutes regardless of non-linearities, because the sub-stepping within each time step does not cause any significant reduction in performance due to its parallel implementation if the adequate number of cores or processors is available.

The time histories will be stored in a HDF5 format with all necessary information for the time parameters (date, duration, number of DOF, number of time steps and duration of time step) and for the time integration (acceleration, velocity, displacement and stresses) for further processing, e.g. Matlab.

Thus, several thousand realistic 3D FE building models are created and simulated under earthquake loading using only a few hours on a regular desktop. Figure 4 shows a small simulated portfolio of 65 buildings using around 500.000 finite elements (1.700.000 DOFs). Approximately 30 % of the buildings have a balcony and 20 % of the buildings have a soft storey.

Figure 4. A regional portfolio of 3D FE-models for masonry buildings simulated with the SBP-Tool. This can be combined with any seismic input, e.g. wave propagation models, Mühlhausen (2012b)

## 5 DEFINING A VIRTUAL PORTFOLIO

The global building stock is highly heterogeneous in terms of design, construction practices and vulnerability to natural hazards.

GEM, the Global Earthquake Model Foundation, delivers in this respect powerful tool to get a better understanding of how to simulate a virtual portfolio in a particular region in the world. On one hand there is the open source Inventory Data Capture Tool (IDCT) and on the other hand the GEM Earthquake Consequences Database (GEMECD). Both applications deliver information regarding the earthquake event itself and a first idea of the building stock. The development of a third tool, and from the point of view of this paper the most interesting one, was launched in December 2010, namely “GEM Building Taxonomy”. This tool intends to provide a classification of building characteristics in an ordered system.

The newest version of the GEM Building Taxonomy V2.0 should be available in March 2013 and will require 13 attributes to describe a building. These are: material of the lateral load-resisting system; types of lateral load-resisting system, roof and floors; height; date of construction; structural irregularity; occupancy; direction (to describe the orientation of the building with different lateral load-resisting systems in two principal horizontal directions); building position within a block, shape of building plan; exterior walls; and foundation, Brzev (2012).

The vision of the GEM Building Taxonomy team is to create a unique description (code) for a building or a building typology.

Although developed independently, both tools use similar or even the same attributes (Table 1) to identify a building or define a portfolio.

The SBP-Tool is written in a generic way that allows adding new attributes from the GEM Building Taxonomy or to modify the currently used SBP-Tool's parameters. This allows the direct use of the GEM Building taxonomy in the SBP-Tool. It also allows further development of the GEM taxonomy with respect to additional criteria needed for risk simulation.

Table 1. The 13 attributes of "GEM Building Taxonomy" and the required input parameters of the SBP-Tool.

| Attribute or SBP-Input Parameter | GEM Building Taxonomy | SBP-Tool |
|---|---|---|
| Material of lateral Load- resisting system | x | x |
| Lateral load-resisting system | x | x |
| Roof * | x | x |
| Floor | x | x |
| Height* | x | x |
| Date of construction | x | x |
| Structural irregularity | x | x |
| Occupancy | x | x |
| Direction | x | x |
| Building position within a block | x | o |
| Shape of the building plan | x | x |
| Exterior walls | x | x |
| Foundation | x | o |
| Further SBP-Tool input parameter for describing a portfolio: | | |
| Number of buildings | | x |
| Number of storeys | | x |
| Dimension of ground plan* | | x |
| Dimension of rooms* | | x |
| Dimension of windows and doors | | x |
| Number of storeys* | | x |
| Number and size of windows* | | x |
| Storey height* | | x |
| Balcony** | | x |
| Soft storeys** | | x |
| Thickness for outer walls | | x |
| Thickness for inner walls | | x |
| Thickness for the roofs | | x |
| Stiffness for outer walls | | x |
| Stiffness for inner walls | | x |
| Stiffness for the roofs | | x |

x Attribute or Parameter is used
o Attribute or Parameter is not used
* A range (minimum and maximum) must be defined
** % of the whole portfolio has this input parameter

## 6 INSURANCE LOSS ESTIMATION FOR VIRTUAL MASONRY BUILDINGS

Loss curves are an important tool for the insurance industry to estimate the potential risk and damage to a building (single risk) or portfolio and can be described by the relationship between renovation costs and return period.

The loss curves in figure 5 and 7 were determined with a sophisticated statistical process that has already been published in Mühlhausen (2010, 2011a and 2011b).

As a first approximation for a crack criterion for masonry, a threshold for the principal tension stress was chosen and also, a linear relationship between costs and damaged area was assumed. These assumptions allow estimating loss curves for a typical building (single risk), using the linear simulation method based on power spectra, as described in chapter 3.

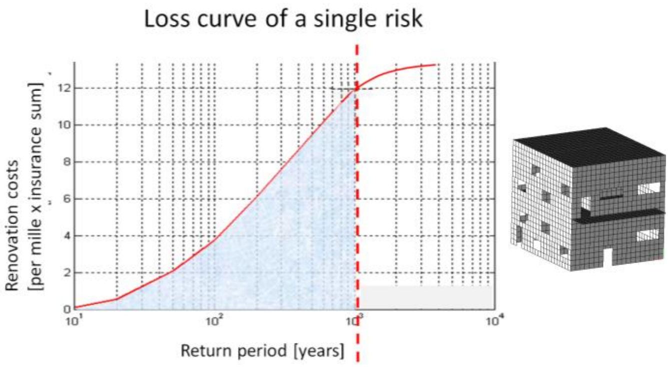


Figure 5. Typical loss curve for one building (right) with the expected linear threshold for masonry buildings, Mühlhausen (2012b)

By looking at four seemingly similar buildings (figure 6) from this study, it is apparent that, the simulated loss curves (figure 7) may be grouped according to certain attributes.

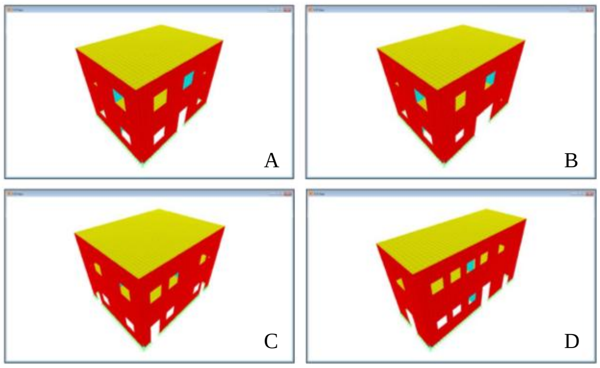


Figure 6. Typical masonry buildings (variant A to D) with sligthly different dimension and openings, Mühlhausen (2010)

In this case, there is a first indication, that the ratio of wall openings may be an important criterion.

Currently, studies are under way to clarify the role of such attributes in insurance loss estimation. Once clarified, such attributes should be made available through GEM's building taxonomy.

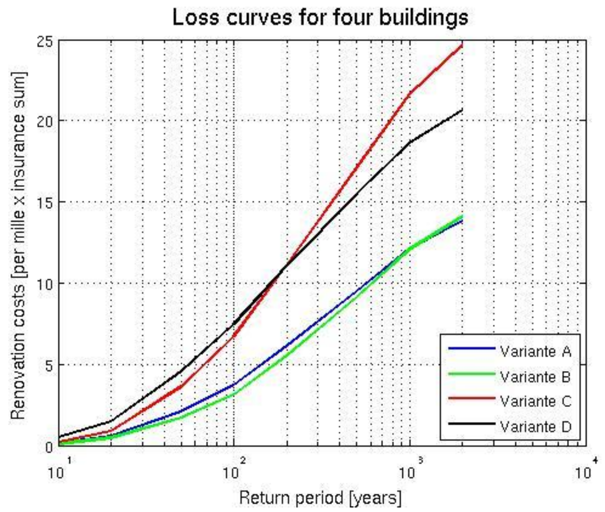


Figure 7. Loss curves for the four buildings from figure 6. Building A,B and C, D may be placed in different loss groups based on their ratio of wall openings, Mühlhausen (2010)

## 7 CONCLUSION AND OUTLOOK

Reliable seismic damage and loss simulation not only requires sophisticated seismological ground models, but foremost detailed structural models, since damage and repair needs depend on the dynamic characteristics and local non-linear structural behavior. Virtual building portfolio consisting thousands of FE models can now be generated with the SBP-Tool developed at the University of Kassel. Their seismic risk can be within a reasonable time frame by using an efficient algorithm in combination with parallel computing.

Although developed independently, GEM's building taxonomy and the SBP-Tool use similar or even the same attributes to identify a building or to define a portfolio. It allows further development of the GEM taxonomy with respect to additional criteria needed for risk simulation.

In this respect, the SBP-Tool can only generate masonry buildings but an extension for other building types (e.g. steel-concrete composite structures) is already under development.

## 8 ACKNOWLEDGEMENT

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