Seismic vulnerability assessment in the framework of GEO: a case study on Messina, Italy.

Diego Polli, Fabio Dell'Acqua, Paolo Gamba

Dipartimento di Elettronica, Università di Pavia, via Ferrata, 1 I-27100 Pavia
{name.surname}@unipv.it

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ABSTRACT:

Earthquakes represent a significant fraction of the global natural disaster bill. Earthquake loss prevention includes evaluating seismic vulnerability, a characteristic of anthropogenic elements expressing their capability of resisting ground shakes. Large-scale vulnerability assessment is currently impractical due to the complexity of the accurate, in-situ based assessment techniques. It thus does make sense to develop methods using remotely sensed data, providing less accurate and precise results, but apt to be used on a much larger scale, for purposes of risk scenario analysis. In this paper some preliminary steps towards Earth Observation- (EO-) based determination of seismic assessment are described through a case study on the site of Messina, Italy, fusing information from very high resolution optical and synthetic aperture radar (SAR) data. These experiments are performed in the framework of GEO (Group on Earth Observation) WP (workplan) 2009-2011 task DI-09-01a, focussed on EO-based vulnerability assessment.

1. Introduction: vulnerability assessment and remote sensing

Models capable of assessing earthquake-induced losses are of fundamental importance for risk mitigation and for emergency planners. One of the main elements in a loss model is an algorithm to evaluate the seismic vulnerability of the buildings. In fact seismic risk depends both on seismic hazard and vulnerability of exposed elements and can be described as the probability of loss at a given site and is obtained through the convolution of three parameters: exposure, vulnerability and seismic hazard. The seismic vulnerability of a structure can be defined as its susceptibility to damage by ground shaking of a given intensity.

Evaluating the vulnerability of existing building stock is certainly pivotal in this framework and indeed it has a long history of method proposed along the years [1], based either on empirical, analytical or even hybrid approaches.

In general, though, the various methods proposed need a considerable amount of information to be collected; for example when the response of a single building is considered, the existing approaches essentially require several studies on the structure as an accurate examination of the possible local mechanisms of damage and collapse, the selection of a probable non linear response mechanism, and so on. This may represent a severe limitation on the geographic scope of the vulnerability estimation procedure, either because historical data are unavailable at the desired precision or format, or because the in-situ collection of data is too expensive and time-consuming to make it practical to collect the required information. Though, it may become feasible once suitable methods become available and trading precision for geographical scope is an option.

Recently, new algorithms have been developed for vulnerability assessment, which require fewer data, normally available from census on the building stock, e.g. year of construction, number of storeys, materials, etc. One of such methods, termed SP-BELA (Simplified Pushover-Based Earthquake Loss Assessment) [2] can provide a sensible output for comparison purposes even with a very limited set of inputs including the footprint of the building and the number of storeys, being this latter a parameter more important than the total height of the structure.

Remote sensing techniques, which by definition can operate on far larger scales than in-situ data collection, can complete the framework. The idea of evaluating vulnerability based on Earth Observation (EO) data has indeed appeared on the Work Plan 2009-2001 of the Group on Earth Observation, the international institute with a mandate to implement the Global Earth Observation System of System [3].

Task DI-09-01a of the GEO 2009-2011 Work Plan is indeed centred on EO-based seismic vulnerability estimation, with a special focus on a limited set of sites ("SuperSites") over which collection of satellite data is prioritized thanks to the Geohazards SuperSites Concept (Geohazards, 2005). EO could be the key enabling technology in large-scale estimation of seismic vulnerability, as it has already happened for e.g. floods and this is very useful for studying risk scenarios and preparation of countermeasures [4].

As mentioned above, the 3D shape of the building is a most relevant input item. In literature it is possible to find lots of building height extraction methods, both for optical and SAR imagery. Existing methodologies are either based on shadow analysis [5] or on interferometric data [6]. However, the calculation of the interferogram fails if all of the roof backscattering is sensed before the double bounce area and therefore superimposes with the ground scattering in the layover region, which is usually the case for high buildings. To tackle the problem of signal mixture from different altitudes methods founded on interferometric or polarimetric data or stereoscopic SAR are proposed [7] [8]. Recently, also methods based on multi-aspect data where the same area is measured from different flight paths, were proposed [9].

Generally speaking, as testified by the amount of relevant literature, the problem of extracting a building 3D shape is quite a complex one. For our purposes, however, such problem can be split into two sub-problems, namely footprint extraction and

determination of the number of storeys. This latter problem is quite a new one in the remote sensing research scenario, and a simpler one with respect to traditional building height extraction.
Our final intent is a wide range scanning of the urban environment, using optical data to extract footprints of buildings and, due to its side-looking nature, using SAR data to extract the number of storeys. These information will then represent the basic input to the vulnerability model .
To demonstrate the feasibility of the approach, we started with a case study on Messina, where a former vulnerability evaluation performed by EUCENTRE could represent a reference point, and a complete SAR acquisition at six different azimuth angles performed by the Canadian firm INTERMAP ® in the framework of a co-operative work with the Remote Sensing Group at the University of Pavia. The paper is organised as follows: next chapter describes the available data, chapter 3 is devoted to feature extraction and fusion, chapter 4 presents the vulnerability evaluation tool and chapter 5 finally concludes the paper with some final remarks.

2. Available data

Messina, Italy was the site selected for this case study. It is a famous city to the earthquake scientist community because of the disastrous 1908 event, which triggered also a tsunami resulting in its almost complete destruction. Several studies are underway on this test site and the 2008 Applied Geophysics Conference took place in Messina to celebrate 100 years of progress in disaster mitigation and management. The vulnerability of Messina building stock was analysed through a statistical approach where the assessment unit was the census tract. In the framework of a cooperative work with the INTERMAP © company, owning and operating its own airborne radar instruments, a 6-fold radar image acquisition over the urban area and the surroundings was performed along 6 different flight lines which resulted in multiple views over each building. The acquisition was performed by the cited company using its STAR-4 © airborne sensor mounted on a King Air © aircraft. An overall data sample is shown in Figure 1. The description of the six flight lines and their directions are reported in Table 1 and Figure 2.

Figure 1 : sample airborne SAR image on Messina urban area.

Image name	Image size	Flight direction	Look direction	Average flight altitude (m)
m9044p1s1	18298x8708	304°	right	7429
m9044p2s1	12494x16505	35°	right	7426
m9045p1s1	13174x9187	124°	left	5606
m9045p2s1	13192x9186	304°	right	5610
m9045p3s1	10334x16830	35°	right	5609
m9045p4s1	10336x16830	35°	right	5608

Table 1: Description of the six flight lines

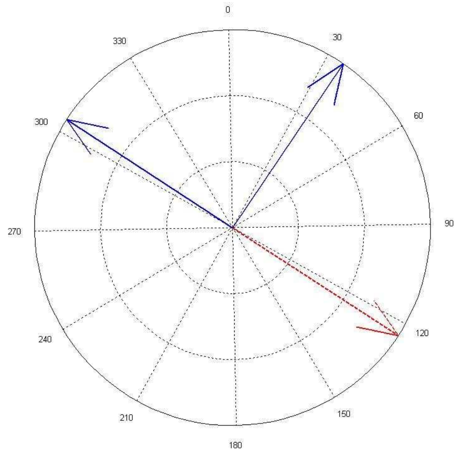

Figure 2: Flight directions, in solid blue line are represented right side look, in dashed red line left side look.

With the future result assessment in mind, a small cluster of buildings constituting a census tract was selected. The 6 geocoded radar images were all cropped to a reasonable buffer area around the selected building and passed on to the next processing steps.
No first-hand optical data is available yet on the selected area so we decided to use Google Earth © (GE) images for our first feasibility experiments. The building was located on the optical GE collage and cropped to a buffer area around it, as visible in Figure 3.

Figure 3 : Google Earth © image of the selected area with the considered cluster of buildings highlighted.

3. Building Feature extraction

Extraction of building footprint, as well as extraction of the number of storeys, is performed relying extensively on linear feature which is part of a in-house developed feature extraction software named BREC [10], described for its relevant part in the following.

3.1 Linear element extractor (w-filter)

To extract linear features in the images we used the first part of a technique formerly developed in our research group [11] for road network extraction. The second part of [11] is devoted to road network optimisation starting from the candidates, which is not relevant for the work presented in this paper, and it is thus not used in this context. Road candidate extraction is composed of a multi-scale feature fusion detector (multiple-feature extraction, feature binarization, multi-scale fusion, and candidate area selection) and a segment extractor (shape regularization and best fitting segment extraction). In order to search for road pixels, the first step in the procedure is the computation of a few spatial features over a straight line of length R centred on the current pixel p(i, j) i.e. angle of maximum homogeneity, total radiance and contrast. Feature binarization step consists of comparing each local feature with the average of its neighbourhood and retaining only the "sufficiently inhomogeneous" pixels, assumed to be good clues of presence of roads. The third step is fusion of the features obtained at different scales, i.e. for different values of R, realised through a logical and operation to maximise reliability of the detected linear features. The fourth and last step in multiscale feature fusion consists of "filtering out" the areas with unacceptable geometric or radiometric characteristics; in other words, areas that are too small or too bright to be road elements in a SAR image. The results undergo the second part of the processing including shape regularisation and extraction of best fitting segments. For more details, the readers are referred to [11]. The final output is a list of candidate roads extracted from the remotely sensed image. In our work this is considered as the set of linear features extracted from the analysed image and a starting point for the subsequent information extraction.

3.2 Building footprint extraction

The footprint of the building was extracted by applying the linear feature extractor to a low-quality, widely available very-high-resolution image, namely the one captured from Google Earth screen. Its poor quality does not appear to be too hard an obstacle, as the extraction result appear to be satisfactory (see Figure 4). Only the closure of the building contour had to be performed manually because the relevant part of the software suite is still under development. This procedure allows to outline the building footprint and to determine its across and along size, two most important parameters for vulnerability assessment.

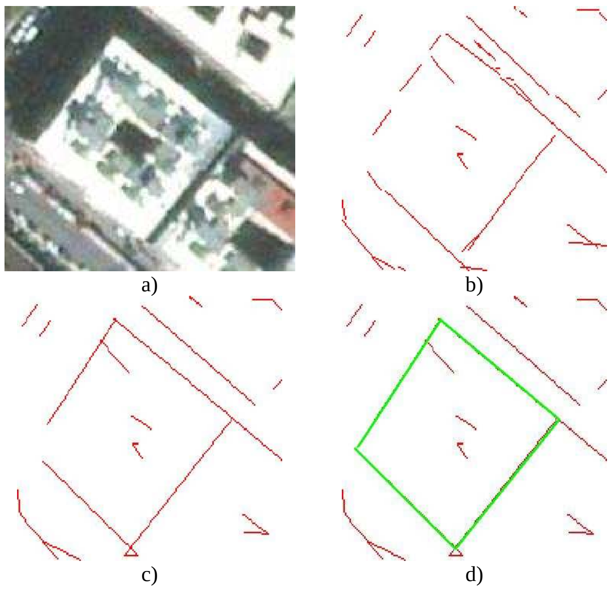

Figure 4 : :steps in generation of building footprint estimate: a) the original grayscale image, b) preliminary feature extraction, c) feature merging, d) footprint hypothesis.

3.2 Storey number extraction

Inspection of the Google Earth image allowed selection of the best azimuth angle among those characterizing the 6 flight lines on Messina. As visible in Figure 5(left side) the most visible building façade is the north-western one as it faces a wide urban road and it is not occluded by vegetation. The corresponding radar image, shown in Figure 5(right side) features quite apparent rows of scatterers, probably originated by the corner structures constituted by the protruding balconies, in addition to the corner reflector structure at the pavement/façade meeting point. If we assume the footprint of the building is available, so is also the dominant direction of the façade in the image. As first step is used a morphological filter in order to enhance the local maxima, a hard decision criteria (strong scatterer/ no strong scatterer) is applied on each pixel. A mask is obtained where strong scatterers are turned into 1's. The mask image is then rotated by the orientation angle retrieved from the optical image. The second step is delete all the isolated pixels using a filter which studies the distribution of the pixels and preserve only the scatterers with a high density spatial distribution. The final step is perform a morphological dilatation using a constituting element whose shape is that of a column of pixel. This way is possible to obtain, starting from single pixels, short segments that create columns marking floors (Figure 6). Quite apparent are here the four parallel lines which mark the associated four storeys. Counting the longest parallel lines extracted from the image results in determining the number of storeys in the building.

Figure 5 : On the left the optical image from GE, on the right side the SAR image of the selected building.

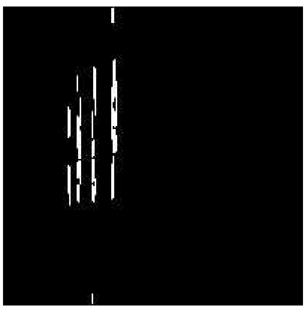

Figure 6 : Segments extracted from north-west facade.

Figure 7 : Segments extracted from south-west facade.

Repeating the same procedure on the next most visible façade, i.e. the south-west one, provides the same result and confirms the one previously obtained (see Figure 7).

The overall information flow is visible in Figure8

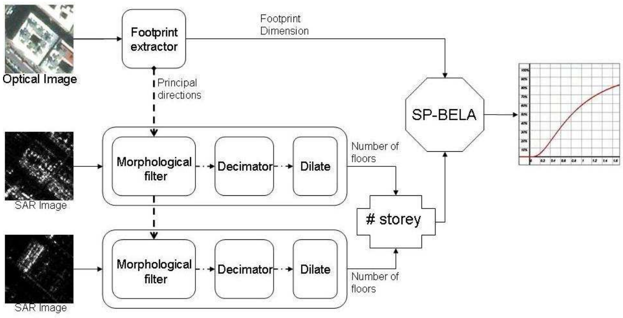

Figure 8 : Flow-chart of the applied method

4. Vulnerability evaluation

The footprint size and shape are finally fed into the SP-BELA vulnerability model for the final assessment. An example of the produced output is shown in Figure 9.

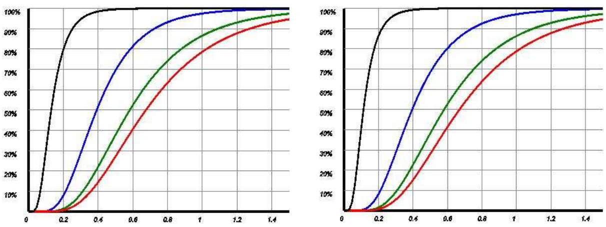

Figure 9 : Vulnerability curves for 3 (left) and 4 (right) floors

To highlight the importance of the storey number extraction, a comparison can be made between the curve in Figure 9, obtained by forcedly missing one floor (left).
Although the statistical significance of this test is questionable and more extensive testing is naturally required, a comparison performed with previously performed assessments, cited in section 2 appear convincing and encourage to move on along this direction.

5. Conclusions and future developments

Some basic elements supporting vulnerability evaluation of buildings using satellite images were presented. The final goal is to set up a system for producing a zero-level estimation of vulnerability relying in principle on remotely sensed data only. Such system would untie at least to some extent the evaluation of the seismic vulnerability from the availability of in-situ data, which is extremely scarce and inhomogeneous if one looks at the problem in a global perspective. Initiatives for large-scale evaluation of seismic risk such as the Global Earthquake Model (GEM, 2008) would be among its possible beneficiaries.
In this paper, the problem of determining the number of storeys of a building in a radar image was addressed, in addition to extracting its footprint size, both characteristics meant to be input to a vulnerability assessment method. Although the method is still to be automatized and tuned, the principle feasibility of EO-based vulnerability is somehow proved, and the next steps of our work will be in testing it on real cases, comparing its outputs with in-situ vulnerability assessment. An agreement is being set up with the Italian Università degli Studi della Basilicata, Department of Structures, Applied Geotechnic and Geology to cooperate and share ground truth data on some municipalities in the Basilicata region. Results will be published as soon as they will be available.

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