A DAMAGE SCENARIO FOR THE CITY OF MESSINA, ITALY, USING DISPLACEMENT-BASED LOSS ASSESSMENT

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ABSTRACT :

An earthquake damage scenario for the city of Messina, Italy, has been carried out with the aim of forecasting the distribution of different levels of structural damage within the city. These results can be of use to the Civil Protection Department and other services for disaster planning management. Field surveys were carried out in order to calibrate the model to the building stock characteristics of Messina. On the basis of these surveys, different structural typologies, which group buildings with similar features, were characterized. The probability of exceeding a given damage state for each group of buildings (which included both reinforced concrete and masonry construction), was computed through a recently developed probabilistic displacement-based vulnerability procedure. This study has highlighted the high seismic risk of the city of Messina, caused by both its high level of hazard as well as the significant vulnerability of its building stock. Work currently underway now aims at the identification of the effects that debris stemming from the collapse of the buildings could have on the road network, with a view to assess if, after a seismic event, rescue and emergency teams would be in a position to access the most damaged areas of the city and then reach the hospitals and other emergency support facilities.

KEYWORDS: displacement-based, loss assessment, damage scenario, Messina

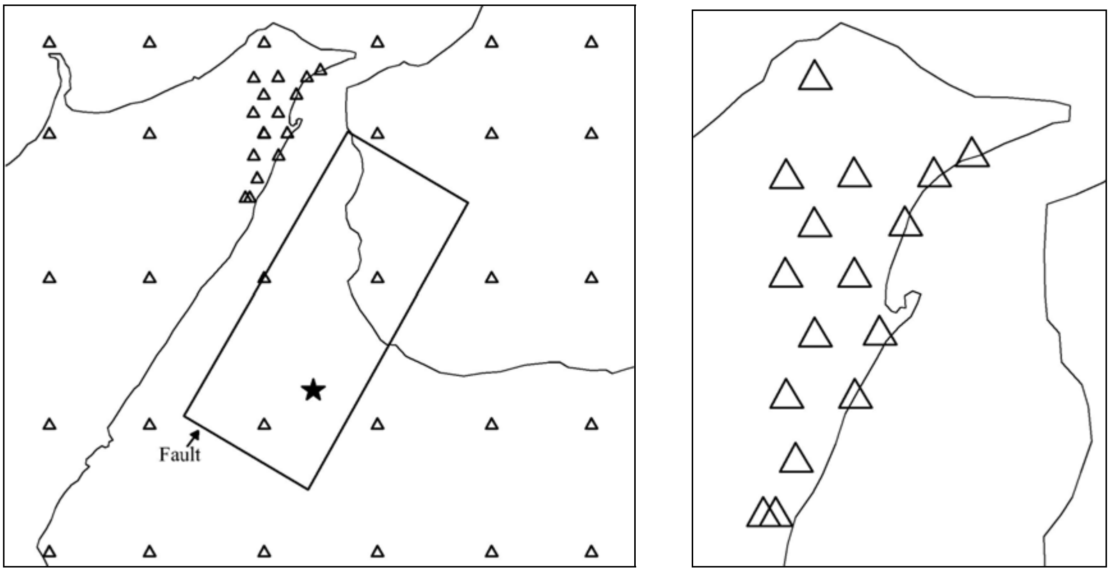
1. INTRODUCTION

On 28th December 1908, one of the most devastating earthquakes in history hit the city of Messina. The magnitude of this event has been estimated in the range of M_w = 6.7-7.1, and it was followed by a tsunami which reached heights of 3 to 12 m and covered the city for about 200 m inland. The earthquake had major consequences for the city of Messina due to the 86.000 victims, more than the 40% of the population of Messina at that time, and the almost complete destruction of the built environment. Field surveys carried out immediately after the earthquake reported that about 98% of the buildings were heavily damaged or needed to be demolished (Baratta, 1910). Aside from the large human casualties, the earthquake caused a serious economic crisis, of which Messina is probably still suffering the consequences. Economic losses connected to that seismic event weighed heavily not only on the city but also on the National budget, because the Italian State had to bear the important reconstruction and repair costs. It has been estimated that the economic losses, computed as the sum of the value of private buildings, public works, public buildings, interruption of public transport and aid costs, amounted to about 600 million Lira (Baratta, 1910); the equivalent of this amount today would be over 2 billion Euros.

Mindful of past experience, and with the aim of avoiding a repetition of the consequences of the 1908 Messina earthquake, a damage scenario for the city of Messina as it is today, based on an earthquake with similar characteristics to that of the 1908 earthquake, has been carried out. The final objective of this study will be to verify whether Messina, one hundred years later, is able to withstand such a seismic event, and if not, provide guidance on how seismic risk can be most efficiently mitigated within the city.

2. EARTHQUAKE SCENARIO

As mentioned previously, the earthquake scenario considered herein has similar characteristics to the 1908 event. There have been various studies carried out to ascertain the main characteristics of the 1908 event, with very different results for what concerns the magnitude and the location, orientation and size of the fault rupture (see e.g. Pino *et al*., 2000). The physical model of the earthquake considered herein does not claim to be an exact repetition of the 1908 event, but it is a feasible event based on the seismograms and other physical evidence which were recorded of the earthquake. Velocity seismograms were generated at various locations within the city of Messina based on the chosen source model of the earthquake in terms of the point where the rupture initiates, the average slip on the fault plane, as well as a three-dimensional velocity model describing the rocks through which the waves propagate. Figure 1a shows the geometry of the fault, the epicenter of the earthquake, and the recording stations where velocity seismograms were generated; a close-up of the locations of the seismograms within the city is shown in Figure 1b.



(a) (b)

Figure 1 (a) Fault geometry, epicenter (shown as a star), and location of the stations where velocity seismograms were simulated (b) close-up image of the city showing the seismogram locations

The damage scenario presented herein has been determined by applying a displacement-based loss assessment method where the seismic demand is modeled using displacement response spectra. The velocity seismograms were computed at the bedrock, hence the soil characteristics have been accounted for by first computing the displacement response spectra from the seismograms and then amplifying the response spectra with the amplification factors which have recently been proposed as part of an Italian project INGV-DPC S5 (2007). These linear amplification factors are functions of period, T, and mean shear wave velocity, V_{s30}. Based on a national study which related a 1:500,000 geological map to site conditions using the Eurocode 8 classification scheme (Amato and Selvaggi, 2002), the whole downtown area of Messina has been assigned to be site class C (V_{s30} between 180m/s and 360m/s). This part of the study will need to be improved in the future based on more detailed geological maps and site classifications. The uncertainty in the demand definition has been accounted for by adding an aleatory variability to the response spectra. This variability is currently based on the values given in typical ground-motion prediction equations until such variability can be estimated through the physics-based model of the earthquake used to produce the seismograms. The mean amplified displacement response spectrum at a single site in the city, together with the 16 and 84 percentile displacement spectra, are shown in Figure 2.

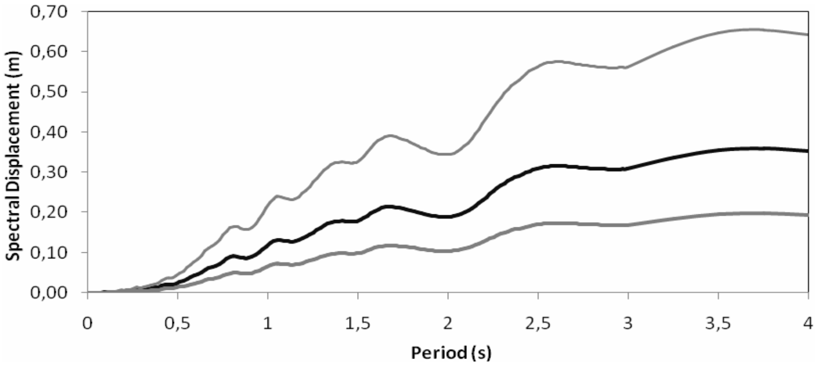


Figure 2 Mean (in bold), 16 and 84 percentile displacement response spectra

3. BUILDING STOCK CHARACTERISTICS OF MESSINA

After the 1908 earthquake, the almost complete destruction of the city meant that a new city had to be rebuilt in its place. In 1911, the Borzì Regulatory Plan was approved which laid out a regular gridded plan for the city with wide streets and maximum building heights of 10 metres. Furthermore, following the 1908 earthquake, the first seismic zonation map was introduced in Italy, specifying the areas which had to be designed to withstand the additional lateral loads induced by strong ground shaking. The loads for which the buildings had to be designed were specified as a percentage of the weight of the building. Messina was immediately classified as seismic Zone 1, corresponding to the highest seismic risk and it was obligatory to design buildings under lateral forces equal to about 10% of the vertical loads. During the reconstruction of the city, the Second World War took place and a series of bomb strikes damaged over 90% of the buildings. Since 1909, updates to the seismic design codes in Italy had been introduced and in the years following the war it was possible to construct buildings up to 5 storeys, and thus many of the 2 and 3 storey buildings in the centre of the city were demolished and new higher buildings constructed in their place.

For the current study, it has been assumed that the majority of the reinforced concrete buildings of the city have been seismically designed, whilst masonry buildings are characterized by either solid or perforated artificial bricks, which are known to have been used in the post-earthquake reconstruction of Messina. In order to define the exposure in terms of the population and buildings, the 1991 ISTAT (National Statistics Institute) Census of the Population and Dwellings has been used. This data is available at different aggregation levels: municipality level, which is useful for regional or national studies, and census tract level, useful for sub-Regional studies. In this study, the data available at the census tract aggregation has been used; Figure 3 shows the main city of Messina subdivided into 849 census tracts.

The Census data in 1991 was collected in terms of dwellings; however, as part of the Census form, each dwelling was classified as being located within a building with a certain number of dwellings (from 1 to > 30), of a given construction type (reinforced concrete, reinforced concrete with pilotis, masonry, other), and with a given number of storeys (1-2, 3-5, >5). Hence, based on the Census forms compiled for all dwellings within each census tract, Meroni *et al.* (2000) have estimated the number of buildings classified according to the period of construction, number of storeys and the vertical structural type within each municipality. The volume of the buildings and the number of inhabitants within each of the aforementioned building types have also been derived. The errors associated with the use of Census data based on the number of dwellings to arrive at the number of buildings are recognised by the authors and have been identified and quantified in some areas of Italy (see e.g. Frassine and Giovinazzi, 2004). However, without the presence of detailed exposure data it is necessary to make some sort of hypothesis in order to obtain the number of buildings of a given construction type and with a given number of storeys. Nevertheless, it is clear that there have been changes to the construction and population in Messina since 1991 and thus it is important to update this 1991 Census information through field surveys of the buildings. These field surveys are currently being carried out building-by-building and will continue over the next few months and years. The buildings in Messina for the present study have been classified into eighteen groups: masonry buildings from one to six storeys; reinforced concrete buildings with regular infill panels from one to six storeys; and reinforced concrete buildings with irregular infill panels (pilotis) from one to six storeys.

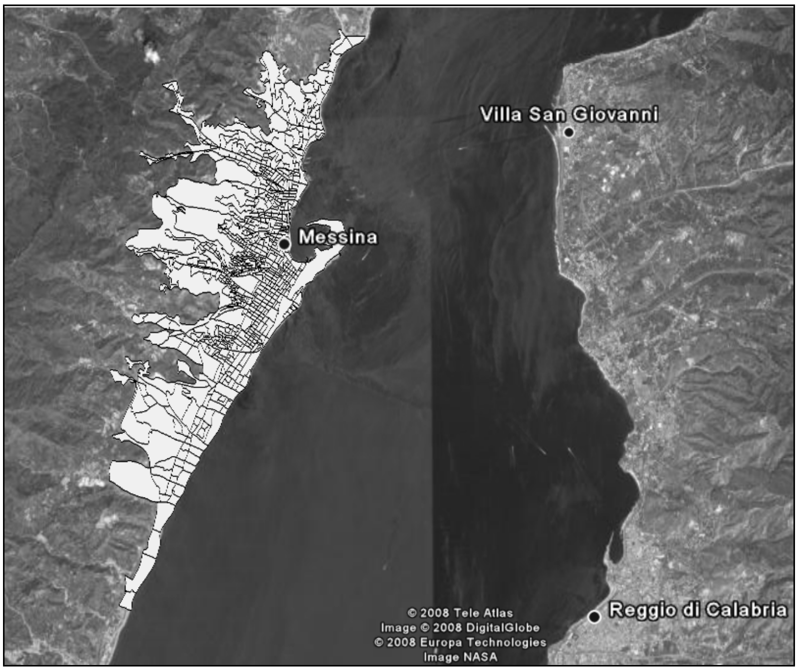


Figure 3 Boundaries of the Census Tracts used in the 1991 Census for the city of Messina

3. VULNERABILITY ASSESSMENT OF THE BUILDINGS

The capacity of each building group has been evaluated using the Simplified Pushover-Based Loss Assessment (SP-BELA) method (Borzi *et al.*, 2008a; 2008b). For reinforced concrete buildings, a prototype 3D structure is defined (see Figure 4) in terms of the number of bays and frames in each direction, whilst the storey heights, span lengths, design loads and material properties are randomly assigned based on pre-defined probabilistic distributions, leading to a simulated population of buildings. Each building in the random population is designed to both gravity and lateral loads in order to define the dimensions of the beams and columns and the amount of reinforcement, and then the lateral strength capacity (or collapse multiplier, λ) is computed by applying a simplified pushover analysis. The lateral displacement capacity of the building at different limit states (slight, extensive and collapse) is calculated based on the rotation capacity of the structural elements using the formulae proposed by Panagiotakos and Fardis (2001).

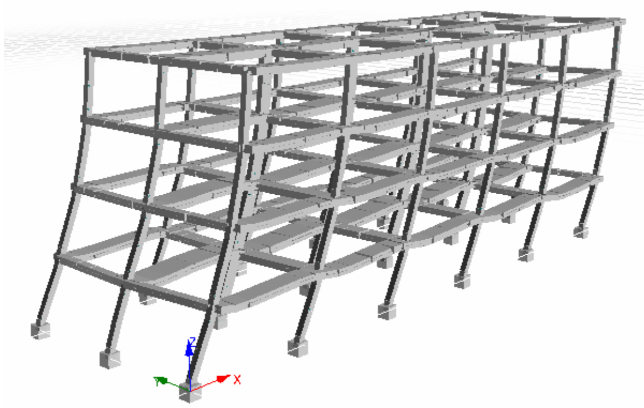


Figure 4 Illustration of the 3D prototype structure assumed for seismically designed RC buildings in Italy

For masonry buildings, the variability in the number of walls in each direction, the area of the floors, the area of the walls, and the material properties has been obtained from survey forms which have been compiled for over 20,000 masonry buildings in Italy. These parameters allow random populations of masonry buildings to be generated and then the lateral strength of each one is calculated using the collapse multiplier equation proposed by Benedetti and Petrini (1985). The displacement capacity at the three limit state states is based on the interstorey drift capacity of different types of masonry, as measured from experimental tests (see e.g. Magenes *et al*., 1997).

The fundamental period of vibration of both the reinforced concrete and masonry buildings can be estimated by calculating the initial stiffness from the simplified pushover curve and the equation of the period of vibration for a single degree of freedom oscillator. The SP-BELA method uses an equivalent linearization approach, and thus the secant stiffness is used to define the period of vibration of post-yield limit states. The displacement demand for each random structure is estimated at the period of vibration of the building and this is compared with the displacement capacity; the probability of exceeding a specific limit state can be estimated from the number of buildings with a displacement capacity lower than the demand, divided by the total number of the buildings in the sample, as illustrated in Figure 5.

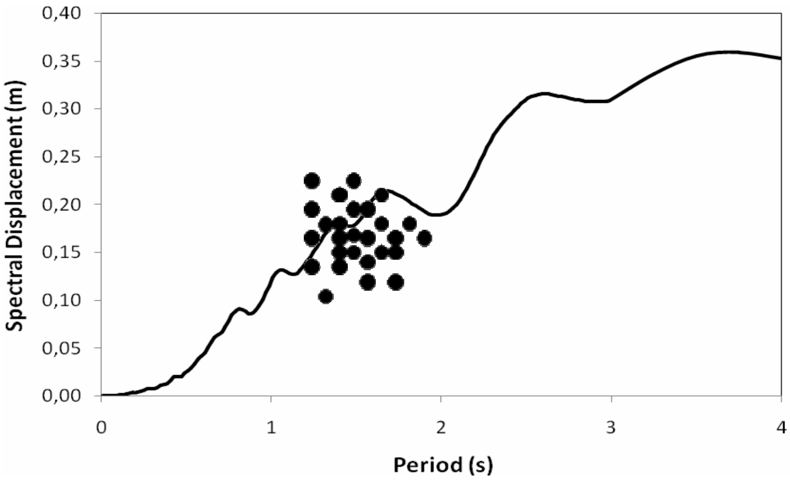
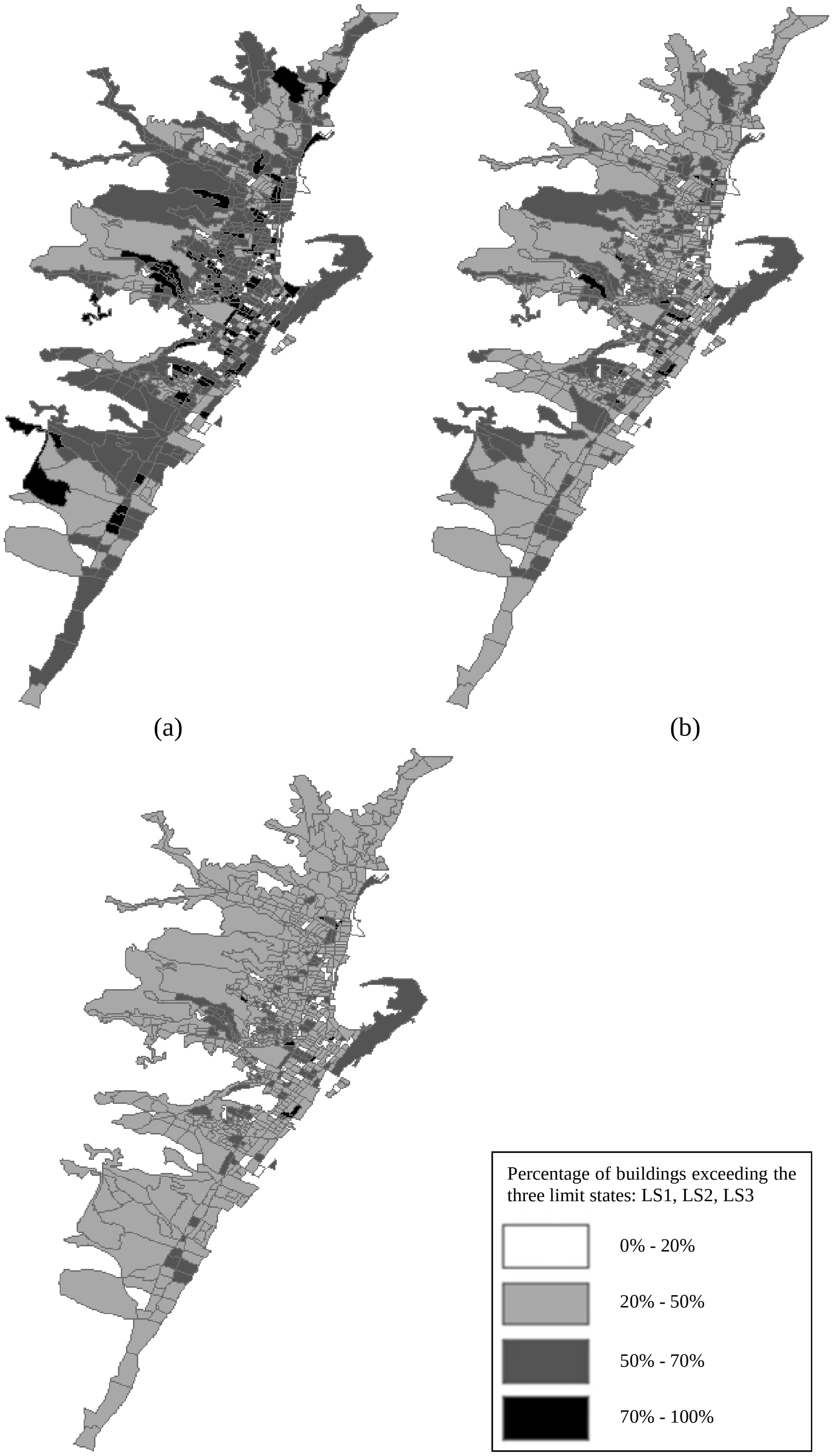


Figure 5 Comparison between the displacement demand and the capacity of the buildings of the random population; each dot represents the period of vibration and displacement capacity of a single structure

The advantage in using this type of method lies in the fact that it can be employed for the assessment of a large number of buildings with reasonable computational effort and it does not require significant details regarding the buildings, because the majority of the building characteristics (section dimensions, reinforcement percentages etc..) are designed as part of the method, according to Italian design codes. The displacement spectra simulated at the recording stations presented in Figure 1 have been interpolated to define a single displacement spectrum within each census tract. This displacement spectrum has then been compared with the capacity of each of the 18 building groups in order to calculate the probability of exceedance of the three limit states. Based on the number of buildings belonging to each group within each census tract, the total number of buildings exceeding the three limit states can be computed by simply multiplying the number of buildings with a given group by its probability of exceedance, and summing for all building groups. The total percentage of buildings exceeding each damage state can then be found by dividing the total number of buildings exceeding the damage state by the total number of buildings within the census tract.

4. DAMAGE RESULTS

The number of buildings exceeding each damage state for each census tract has been calculated and by summing all the results for all the tracts, a probable damage scenario for the city of Messina for an earthquake with similar characteristics to the Messina 1908 earthquake has been derived. This study predicts that if such an earthquake were to occur today in Messina, 52% of the buildings would be more than slightly damaged, with 44% of the buildings exceeding a significant damage limit state and 38% of the buildings collapsed or near collapse. Figure 6 presents the proportion of buildings exceeding each damage state in each census tract.



(c)

Figure 6 Percentage of buildings exceeding (a) limit state 1 (LS1, slight damage) (b) limit state 2 (LS2, extensive damage) and (c) limit state 3 (LS3, collapse)

As can be noted from Figure 6, the majority of the census tracts are characterized by a percentage of 50% to 70% of buildings exceeding the slight damage limit state, but there also quite a large number of tracts with a percentage between 70% and 100%. For the limit state of significant damage, almost half of the tracts have a percentage between 20% and 50% and the other half a percentage between 50% and 70% exceeding the limit state, whilst for the collapse limit state almost all the tracts are characterized by a percentage of buildings between 20% and 50%, and there are even some areas where the percentage is as high as 50% to 70%.

The damage scenario outlined herein provides evidence for the high level of seismic vulnerability in the city of Messina, and underlines how planning a seismic protection plan for the territory is of utmost importance. This plan should characterize the building damage susceptibility and the subsequent structural interventions needed to render buildings able to withstand high magnitude earthquakes. The scenario damage maps are also useful to evaluate the damage distribution in the city immediately after the earthquake, allowing evaluation of the most damaged areas, which would need to be prioritized for emergency aid. If this damage map is superimposed on the city road network (as shown in Figure 7), the resulting map represents an important instrument that can be used to locate practicable roads, free from debris stemming from the collapse of buildings, that could be used to reach hospitals and plan safe escape routes.

Figure 7 Superimposition of the damage maps on the Messina road network (note that the scale is the same as in Figure 6)

5. CONCLUSIONS

In the work described herein, a procedure for the evaluation of a damage scenario for the city of Messina has been presented. The results obtained have highlighted that, although a century has passed since the devastating 1908 earthquake and although seismic design of buildings was introduced after the event, if such an earthquake were to occur today, a large and unacceptable number of buildings would suffer significant damage and collapse, causing loss of life and considerable economic losses.

It is important to underline that a better knowledge of the territory and the buildings, supported by field surveys that are necessary to evaluate the effective level of maintenance of the buildings, would allow the model presented herein to be updated and would render it more refined and detailed. Field surveys, accompanied by expert judgment of professionals familiar with the city and involved in the design and construction of the buildings, would lead to a detailed and reliable building-by-building database which would include those buildings built after 1991. The information included in the database would comprise geometrical and material properties, structural and infill typology, mean storey heights and so on. It is also important to include in the database the soil characteristics beneath the buildings, in order to generate ground shaking scenarios that are consistent with the territory of Messina.

To date, some specific studies have been being carried out on a small proportion of the buildings in Messina that were built in the 1930's and that are considered as representative of a structural typology very common in different areas of the city. The accurate analysis of representative buildings is extremely important because it will allow the general model used for the damage scenario evaluation herein to be further refined and calibrated by directly using the building characteristics within the city.

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