5. ASSEMBLAGE AND ANALYSES OF THE BUILDING INVENTORY IN CATANIA

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5.1 Introduction

Catania is a medium-size city, presently having some 500.000 inhabitants in an urban area that exceeds the municipal boundaries. We remind that it was catastrophically hit by two M~7 earthquakes in 1159 and 1693, and damaged by a few other earthquakes. After the 1693 disaster it was entirely rebuilt and its large expansion after 1945 occurred in the absence of earthquake norms for buildings (enforced in the municipality only since 1981)

For its high vulnerability and hazard, Catania is representative of he situation of several important cities of Southern Italy and in other Mediterranean countries facing a high seismic risk exposure.

A basic aim of this Project is the estimation of direct damage to residential buildings, in the assumption that the impact of such damage in Catania would be dominant in terms of life and economic losses in case of a repetition of the 1693 earthquake. Damage evaluation for other structures, such as bridges and viaducts, churches and ecclesiastic monuments, or induced damage on natural environment (liquefaction) are also of interest in the Project and are described in the other contributions.

Briefly, the residential buildings in Catania can be classified into the following groups (see Faccioli *et al*., 1999):

- masonry buildings, which separately include
  a) those erected in the 18th and 19th centuries (regular and well constructed, with double-leaf walls of well cut volcanic stone, cemented with good quality puzzolanic mortar, and vaulted ceilings);
  b) those built until the late 1950es for lower-class people (originally with one story only and now two stories, usually with volcanic stones more coarsely cut, and with low inter-story height);
  c) those erected in the 20th century (with unreinforced masonry walls and steel or concrete stories, three to four stories, good connection between walls and stories)
- reinforced concrete (R.C.) buildings, which started to be diffused after the war: they are up to 8-9 stories in height and with hollow-tile infill walls. Their in-plan regularity - if present - may increase their vulnerability level (Faccioli and Pessina, 1999). The situation has changed after 1981 when norms for the seismic design of new buildings were enforced in the municipality.

The distribution of masonry and R.C. buildings according to number of stories and year of construction (age class) is shown on Fig. 5.1, based on a considerable part of the most accurate data sample available (so-called LSU survey, described below).

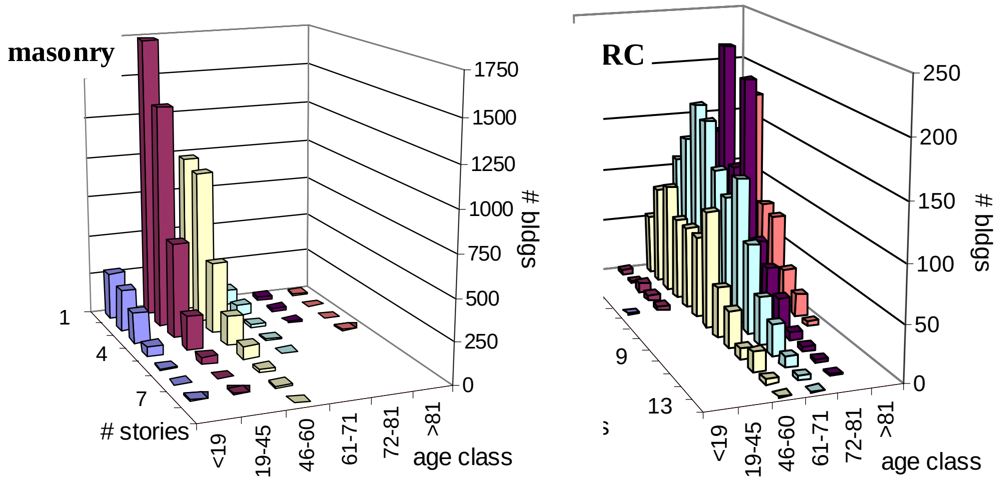

Figure 5.1 - Distribution of buildings by age class and number of stories for masonry (sample of 7757 buildings) and for R.C. buildings (sample of 3355 buildings). The data are from the LSU survey (updated as of January, 1999).

As already mentioned, the historic centre of Catania was completely reconstructed after the 1693 earthquake. It is a remarkably uniform urban system because its urban texture (the street-plan was completely changed during the reconstruction), architectural style, and dominant structural types (masonry) are all of the same age, and they were affected by limited change until the early 19th century (Dato, 1983). Figure 5.1 depicts the growth of the urbanised area over the last century: the age-class distribution makes evident the large post-1945 expansion of the city, characterised by the diffusion of the R.C. buildings, typically up to 8-9 stories in height, and it corresponds to the post-war increase in population (from some 250.000 inhabitants at the end of the war to a peak of 400.000 in 1971).

The development of a complete inventory of structures is a crucial problem in seismic risk analyses: even when data are available (even if they are not aimed at vulnerability analyses) much time and efforts are required to collect them, to check their reliability and to organise a structured database. More expensive still, and time consuming, is the collection of *ad hoc* data, often impossible to realise in case of a large area (Rojahn *et al.*, 1997). If one restricts the collection of data to buildings only, the elaboration of an inventory for a city is still hard because of the difficulty of classifying part of the built environment by well-defined structural and age categories. Indeed the original conditions of the structures could be seriously modified by unrecorded post-earthquake repairs, additions and modifications intervened in the course of centuries.

A relatively detailed description of the characteristics and limitations of the data available on the Catania buildings is provided, because the difficulties and uncertainties arising from their quantitative treatment can be considered typical for cities in seismic regions of Italy.

Building data for the Catania municipality are available from three different surveys, i.e.:

– The nation-wide census of dwellings, or ISTAT (Italian Institute of Statistics) census tracts;
– A survey limited to the central city area, denominated CONARI, used only in the initial phase of the work (and only shortly described here);
– An *ad hoc* local survey of all buildings in the city area, denominated *LSU (Lavori Socialmente Utili).*

The ISTAT data derive from a census of population and residential dwellings, made every ten years for statistical purposes, while the LSU survey data have been gathered by technically skilled people aimed at surveying each building of the city for a vulnerability evaluation. Because of the significant differences, a comparison of the level of detail and reliability between the two surveys is shown in Table 5.1.

Table 5.1: Comparison of the features of the ISTAT and LSU census

Features	**ISTAT**	**LSU**
Date of the census	1990	1998/9
The census provides info on building units	No (to be derived from dwelling)	Yes
Residential units are surveyed	Yes	Yes
Public or/and strategic units are surveyed	No	Yes
Survey made by skilled people	No	Yes
Survey made with the aim to estimate vulnerability	No	Yes
Survey of all the city	Yes	Yes

5.2 ISTAT data

The ISTAT (Italian National Institute of Statistics) survey is a nation-wide census of dwellings that provides such basic information as type of structure (masonry, RC, other), period of construction, number of stories, and state of efficiency. Data for residential buildings are collected in the *"13th general census of the population" (13° censimento generale della popolazione,* ISTAT, 1991), while public or industrial structures of any type are not included.

As data are available grouped in census tracts, a statistical model is necessary to transform the original data about dwellings into building units over the same tract, that cover the whole municipality, with the possibility of significant errors.

The ISTAT census does not provide the number of buildings in each census tract. Indeed, the number of surveyed apartments, included in the building, is recorded, in classes, in the item named “Nr. of building apartments”. For the evaluation of the buildings number in each census tract, the corresponding average values of the class was adopted, and the sum of the building's fractions was calculated.

As for the evaluation of the volume of the buildings in each census tract, the information has been obtained from the ISTAT item containing the apartment's surface, duly modified taking into consideration the building parts not surveyed with the ISTAT residential building form. The ISTAT item named "Surface" has been multiplied by a correction code considering also the parts of the building of rural or non-residential use. Finally, the result has been multiplied by an average height of 3 meters since the real height is not surveyed with the ISTAT form.

Due to this elaboration, the number of buildings and their attribution to a structural class (masonry or RC) can be affected by significant errors (see comparison later, in sub-sect.5.5).

The ISTAT data have been classified according to the typological classes of Table 5.2.

Table 5.2: Typological classes of building surveyed by ISTAT

Structural Typology	**Buildings Age**	**Number of Stories:**	**Structural Context**	**State of Maintenance (*)**
Soft story R.C. bldgs **R. C. Buildings** **Masonry Buildings** **Other Typology**	< 1919 1919 – 1945 1946 – 1950 1961 – 1971 1972 – 1981 > 1981	1 or 2 3, 4 or 5 5 or more	Isolated bldgs Block of bldgs	good low

(*)The state of maintenance is a key parameter to judge the seismic performance of buildings but unfortunately is not provided in these exact terms in the Census. Nevertheless, a degree of correlation has been found between houses with low levels of vulnerability and houses where efficient utilities (like water, or modern gas and electrical facilities) exist. This information which can be gathered from the Census data has been therefore taken as synonymous of good state of maintenance (in case of efficient plants) or bad (in case of old and badly wired utilities).

In each census track we have evaluated for each building typology the percentage of the number of buildings, the percentage of the overall surface and the percentage of inhabitants living in the buildings at the census age. All this data has been stored in the *Arc/Info* coverage.

For some census tracts there were no ISTAT data associated. It is the case of tracts where public buildings (hospitals, schools, strategic buildings), historical monuments or empty areas (parks and gardens, squares, etc.) are present. Because of the importance of these structures during the first emergency phases, they were identified and located on a map for city planning purposes.

5.2.1 *The GNDT database*

A statistical approach based on vulnerability score attribution has been used to estimate the damage levels (see section 11). It makes use of a vulnerability index estimated at a national scale through the survey of buildings in many regions of Italy.

About 13.000 buildings (11433 masonry and 1409 R.C. structures) have been surveyed with the so-called I and II level GNDT vulnerability forms (GNDT, 1993), equally distributed between public (5849 bldgs) and residential (5238) constructions (see table 5.3). The census covered 9 regions, scattered all over Italy, as shown in Fig.5.2. The adopted tool in the data collection procedure is the "Form for exposure and vulnerability survey", for masonry buildings, by (Benedetti e Petrini, 1984) and its improvement during the years (GNDT, 1994).

Table 5.3: Forms stored in the GNDT Vulnerability Data Bank (without the LSU data)

	Public buildings	**Residential bldgs**	**Total**
Masonry	5534	5899	11433
R.C	1085	324	1409
Soft-story	23	11	34
Industrial Sheds	205	4	209
Total	56847	6238	13085

The data have been collected in the so-called GNDT vulnerability Data Bank for the calibration of the vulnerability function of buildings.

A statistical approach has been developed for this purpose (Colonna *et al.*, 1994; Meroni *et al.*, 1999) to carry out a vulnerability assessment at a large scale, using the GNDT database and ISTAT data. Indeed, although the method for evaluating single buildings vulnerability by the I and II level GNDT forms is quite well defined, it cannot be applied to each building because of its cost in money and time. To avoid this waste of energy, all the surveyed buildings of the GNDT database were re-classified in the same set classes of Table 5.2, in order to assign a vulnerability description based on structural type, age, number of stories and maintenance level. Then, a statistical processing of the vulnerability index obtained from this data gives a vulnerability distribution for each class of buildings identified in the census data. Finally, for each census tract, one can estimate an average

Fig. 5.2 - Distribution of the Districts in which buildings have been surveyed with the I and II level GNDT forms.

vulnerability index weighing the average vulnerability value on the volume of buildings belonging to each ISTAT class.

The vulnerability indexes used in the present Project (see section 11) are not definitive because new data (LSU data, see below) are available and validations are under way.

5.3 CONARI data

The CONARI survey, carried out in the late 1980s by the Catania city plan office, covers essentially the historic centre and some neighbouring sections of the city (see Figure 5.3). The CONARI data collection had not been designed for vulnerability assessment purposes and it covers about 5000 units. In the CONARI dataset older masonry buildings (over 2000 units erected before 1919) largely predominate on R.C. buildings (about 270 units after 1945, mostly recent downtown office and hotel buildings).

The CONARI data have been used in the first phase of the project (when LSU data were not available), to test the validity of number of buildings estimated by ISTAT data and, successively, they have been used to define a significant sample of building to be surveyed a vulnerability and probability of collapse evaluation (see sub-section 9.5)

5.4 LSU data

Since 1995, a systematic survey has been carried out in seven regions of Southern Italy, most of them with high risk exposure degree, by means of technicians temporarily out of work in the framework of the "Lavori Socialmente Utili"(LSU) project. This project has been funded by the Italian Labour Ministry and the Civil Protection Department, with the scientific-technical support of GNDT. The census examines the public buildings of all municipalities in the investigated regions, plus a sample survey on private buildings and the historical monuments inside national and regional parks in the considered regions.

In some towns, the complete building stock has been surveyed by means a simplified field form elaborated by a GNDT research group that monitored the entire project and trained the people who carried out the survey. This is the case of the city of Catania where a comprehensive survey, specifically aimed at the seismic vulnerability assessment of residential buildings, has been carried out from 1995 to date. The survey teams compiled the appropriate form localising the buildings of each aggregate on a 1:2000 photogrammetric map. The structural information could be directly obtained during the survey, or easily deducted using some default data calibrated in previous surveys.

As the electronic recording is still under way at the time of this writing, the results of the LSU survey presented in this paper are still partial. The LSU survey has so far (November 1999) provided uniformly processed data on some 12900 buildings, more than 2/3 of the total building stock in the city area. Figure 5.3 shows the location of the surveyed aggregates: out of a total of 18997 surveyed buildings, 12503 are masonry and 5494 are R.C. structures.

Each buildings have to be correctly identify inside the aggregate on the map. This procedure, that consequently will improve the risk analysis, is under way by a collaboration of the local Administration, the GNDT and the SSN (National Seismic Service).

The aim of the LSU survey is to gather the information directly required for evaluating vulnerability, including building geometry (height, number of stories, shape in plan), horizontal and vertical type of structural members, roof system, regularities, occupancy, and state of the building (see Cherubini, 1997 for general information on the LSU survey).

The structural information has been successively used in a method specially developed to evaluate a vulnerability level for each building; this evaluation has a grade of confidence larger than that estimated by the GNDT national database method (previously described), and smaller than that obtained by the I and II GNDT level form. In an initial vulnerability analysis the data have been grouped according the classification of ISTAT data (age classes, number of stories, etc. as in Table 5.2), but the statistical inconsistency of some classes has made it necessary to reorganise the data in larger classes (Dolce, 1998).

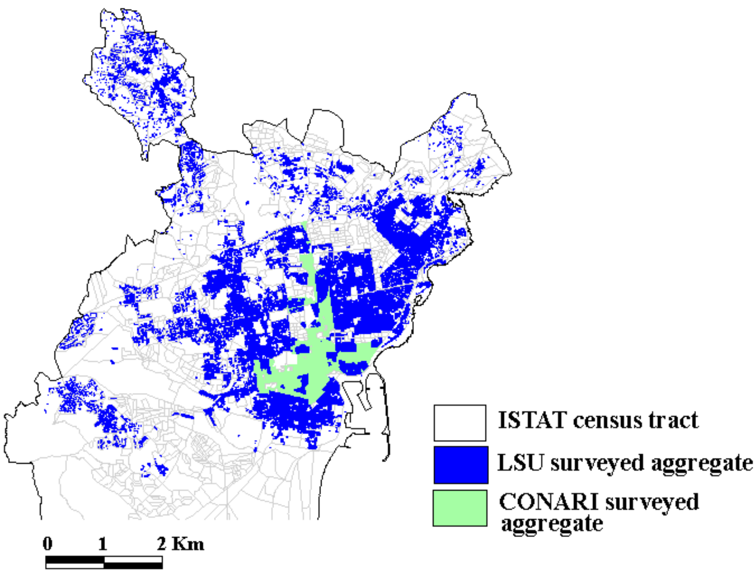

Figure 5.3 -Distribution of the surveyed aggregates by LSU census (update to November 1999) and CONARI census in the centre of the city.

Lastly, the LSU data also include a subset of 380 masonry public buildings, that were surveyed in detail by the I and II level GNDT methodology, well known in Italy and in other European countries (see the case of Lisbon, D'Ayala *et al.*, 1997).

The comparison between the vulnerability index of the masonry public buildings in Catania with that of the GNDT databank (masonry national average) is depicted in Figure 5.4. No index is available for public buildings built in the period 1972-1980 because of the inadequacy of the sample in that class; for the other classes the vulnerability index Iv of public buildings is included between the Iv value corresponding to the best situation for masonry structures (single building of 1-2 stories with a good level of maintenance) and that of the worst state (the building is part of an aggregate and has more than 3 stories, with a bad state of maintenance).

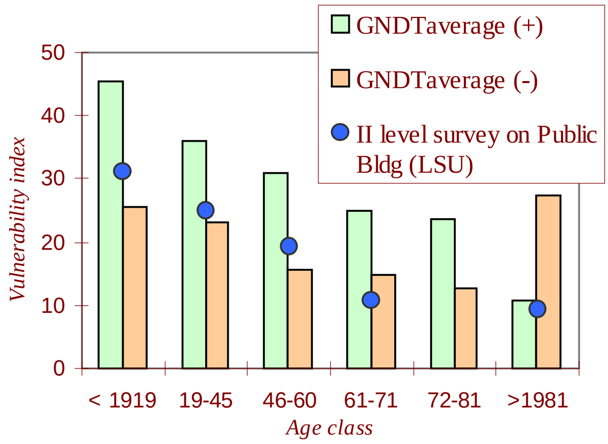

Figure 5.4 - Comparison of the vulnerability index evaluated from the GNDT national data bank and that of the public buildings in Catania surveyed with the II level form by the LSU project

5.5 Data analyses

By comparing the ISTAT and LSU data for those census tracts for which the latter are presently available, the ISTAT database errors on the number of buildings in the different classes can be identified and corrected.

Figure 5.5 indicates that the age distributions of masonry and R.C. buildings according to the LSU and ISTAT datasets.

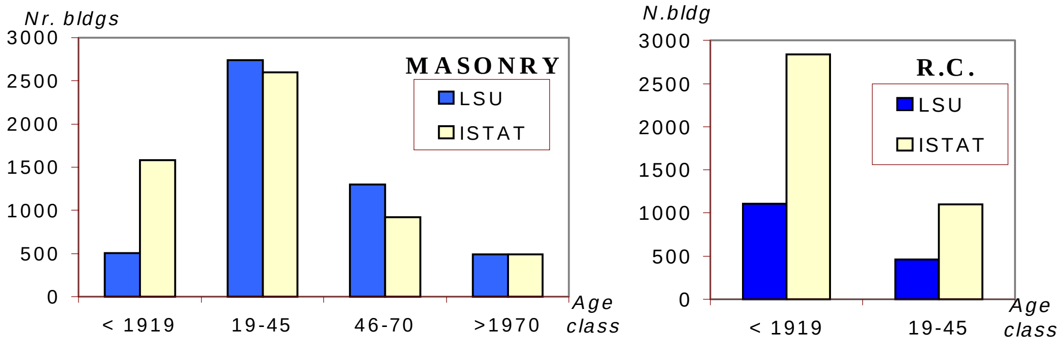

Figure 5.5 - Comparison between the distribution of LSU and ISTAT data for masonry and R.C. buildings in Catania

The distributions of masonry buildings are similar for the post-1919 age classes but substantial overestimation occurs in the ISTAT data for buildings built before 1919. In the historic centre the comparison made between the CONARI and ISTAT data shows also the same trend. In the case of R.C. buildings a general overestimation in the ISTAT data occurs for each age class.

In conclusion, in a first stage of the Project, a building inventory for vulnerability and damage evaluation in the whole city has been assembled by taking the CONARI database for the historic centre, and the uncorrected ISTAT data elsewhere (see flow chart in Fig.5.6)

In a second stage the ISTAT inventory has been modified based on the LSU data: the building inventory in the whole city has been assembled by taking the uncorrected ISTAT data for the historical centre (where the masonry buildings are prevailing), and by correcting (dividing by 2) the ISTAT inventory through the LSU data elsewhere.

Once completed, the LSU survey will allow us to assess and map the vulnerability distribution virtually building by building in the entire city.

As an alternative method was used in the damage evaluation, based on the Limit State approach (see section 11), Fig. 5.6 shows how the inventory data has been advantageously used in this more innovative evaluation.

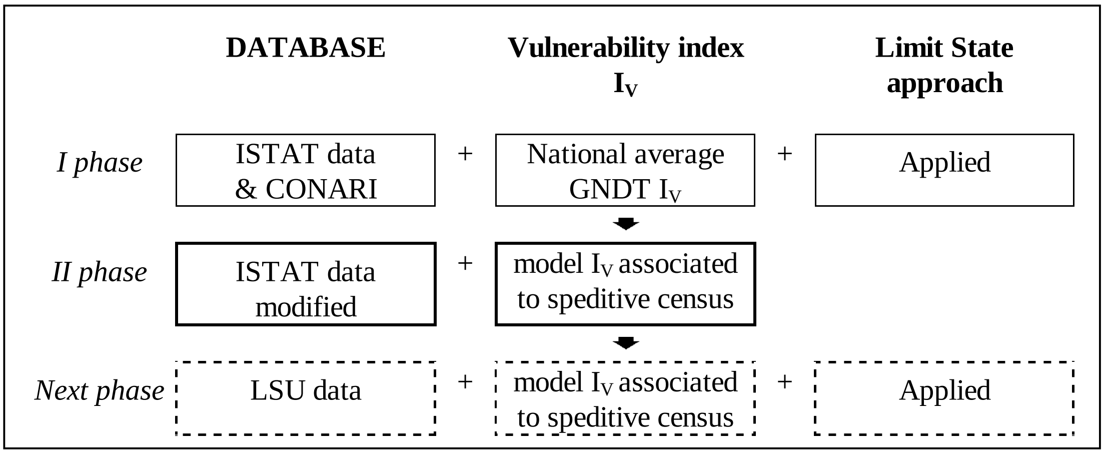

Figure 5.6 - Flow chart of the temporary phases of the Project execution

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