The interdisciplinary activity for seismic risk analysis in a Mediterranean city

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Abstract

The seismic risk analysis evaluation in the Mediterranean area is one of the main tasks for the preservation of Cultural Heritage and for the sustainable development of Mediterranean cities. The Mediterranean area is characterised by medium-high seismic risk, so that earthquakes are the major cause for the destruction of monuments and residential and industrial buildings. A case history of the seismic risk analysis is presented for the city of Catania (Italy), which has been destroyed many times in the past by the 1169 earthquake (XI MCS), 1542 earthquake (IX MCS), 1693 earthquake (XI MCS), 1818 earthquake (VIII MCS) etc., which caused several thousands of deaths. Fault modelling, attenuation laws, synthetic accelerograms, recorded accelerograms, site effects are considered for the evaluation of the seismic action. Vulnerability of the physical environment related to the presence of cavities and to seismic induced landslides and liquefaction is analysed, with special reference to the new modelling of such phenomena and to the application of the models to given areas. The soil-structure interaction has been analysed for some geotechnical works, such as shallow foundations and retaining walls, by means of physical and numerical modelling. Vulnerability of monuments and buildings has been evaluated with the aim of estimating the seismic resistance required to resist the seismic action given by the earthquake scenario. For the mitigation of seismic risk, structural improvements of R.C. buildings with different methodology and techniques are proposed, as well as guidelines for the strengthening of the buildings. The seismic risk of the city is not a summation of the seismic risk of each building, because the vulnerability of the urban system plays an important role on the seismic risk evaluation of a given city. To this aim the vulnerability of road infrastructures, lifelines and urban framework have also been analysed.
1 Introduction

The main research activities of the Research Project for the mitigation of the seismic risk of the Catania city are related to: characterisation of the expected ground motion and site effects; vulnerability of physical environment, road infrastructures and urban system; vulnerability and seismic structural improvement of buildings to prevent damage. For each of these research topics the research activities and goals to be achieved are reported in the following.

The main goals for the characterisation of the expected ground motion and site effects are: source modelling of the Scenario Earthquake; detailed geological survey and geological mapping of the urban area of Catania; noise measurements; site effects evaluation; synthetic accelerograms at the surface and at a given depth (bedrock).

The main goals for the vulnerability of physical environment road infrastructures and urban system are: test sites including borings located at the relevant sites; in situ tests performed inside boreholes, undisturbed sampling and laboratory tests in the dynamic field for detecting soil non-linearity behaviour; updating soil dynamic parameters and geotechnical mapping, including all borings, all geophysical measurements and all in situ and laboratory test results; seismic microzonation of the urban area of Catania; modelling of the vulnerability of slopes to the Scenario Earthquake and application of the model to the Monte Po landslide behaviour, located in the urban area of Catania; modelling of liquefaction including instability due to lateral spreading; evaluation of soil-structure-interaction; survey of the cavities under the Catania area and implementation of a database of detected cavities; road infrastructures vulnerability, including evaluation of seismic instability of slopes, embankments and retaining walls which can cause interruptions on the road system; urban system vulnerability evaluation.

The main goals for the vulnerability and seismic structural improvement of buildings to prevent damage are: assessment of the construction typology, identification tests and evaluation of vulnerability and earthquake resistance of monumental buildings; evaluation of building vulnerability and earthquake resistance for the most common construction typology of R.C. buildings; evaluation of critical acceleration, for limiting state serviceability vulnerability for most common construction typology of R.C. buildings; remedial works for most common construction typology of R.C. buildings; remedial works for most common construction typology of R.C. buildings with traditional and innovative techniques; Code of Practice for the improvement of the most common typology of R.C. buildings; transfer of the Code of Practice to the Municipality and other Institution; transfer of the Code of Practice to the Engineers and to the Technicians; transfer to the Municipality office a Land Information System (LIS) database of all the results obtained by the Research Project; criteria for priority on the remedial works execution.

2 Characterisation of the expected ground motion and site effects

The goal was to provide an alternative characterization of the sources of the January 1693 events, which might suggest a modification of the current seismic
zoning of the SE Sicily area. The geological, geophysical and laboratory investigations performed provide additional constraints to the surface geological setting of the area as well as to the parameterization of the physical models. Numerical simulations have been applied with the twofold aim of estimating strong ground motion scenarios for different earthquake hypotheses and evaluating the effectiveness of 1-D non-linear and 2-D linear methods for the estimation of the local response.

2.1 Characterization of earthquake sources

An updated intensity data-base has been inverted automatically, to improve the source characterisation. After treating, by the grid-search technique, various macroseismic intensity data sets of the two destructive earthquakes of 1693 in SE Sicily, automatic inversions of two updated intensity data-bases by Barbano and Rigano [1] have been performed. The principal geometric and kinematics source parameters of the events have been retrieved by the inversion procedure. The January 9 and 11, 1693 sources - constrained by our inversions - form a NNE oriented segmented fault, approximately 60 km long. In conclusion, the retrieved inland complex fault is steeply dipping towards ESE, or WNW, with rupture mechanism from pure strike-slip to 50% strike-slip and 50% dip-slip. This active structure would cross SE Sicily from the Hyblean Plateau to the coast of the Ionian Sea, south of the city of Catania. At the limit of the negative error of the dip angle at a value of 54° makes our line source for the January 11 event compatible with the trace of the Scicli-Ragusa-Monte Lauro active transcurrent fault found in the field, which outcrops 12-14 km to the west.

This study shows that not all features of the January 1693 events have been completely understood. For instance, as a result of another GNDT project “Evaluation of Geological Hazards in the Seas around Italy: earthquakes, Tsunamis and Submarine Slides” [2] show that the Iblean-Maltese fault system has a very complex structure, and although they find that the principal extensional fault (about 50 km long) can be associated to the 1693 event, they also emphasize that the partitioning between the different fault styles as well as the seismogenic potential of each structure is still to be established. This research provides an alternative characterization of the reference source commonly associated to the January 1693 earthquakes, and the aim was not to provide an alternative reference earthquake for the ground motion modelling, but rather to provide suggestions for updating the seismogenic zones of SE Sicily.

2.2 Geological studies

A detailed geological survey of part of the historical downtown has been carried out, therefore improving the previous geological map of Catania [3]. This study provides a more detailed mapping of the surface formations, and the results have been used to define the shallow layers of the ground motion simulation models, employed for the evaluation of site effects.

2.3 Geophysical investigations

Several new microtremor measurements have been performed in test sites located both in Catania downtown and in the surrounding areas interested by
tectonic structures. Noise measurements in both public historical and private buildings as well as in sites located nearby cavities have been performed. Moreover, a set of microtremor measurements has been performed with the aim of investigating the effectiveness of such kind of measurements to detect amplification effects due to the presence of faults. The analysis and interpretation of a set of noise measurements have also been performed [4]. Results of microtremor measurements will be compared with 1-D modelling in order to validate them and to interpret H/V amplification peaks in term of the geological features of the study area. The interpretation of the noise measurements, i.e. the presence of a HVSR peak and the value of the fundamental resonant frequency, has been used to detect the presence of acoustic impedance contrast beneath the surface soils and spread the shear wave velocity information over patches of the area. These results have also been used to define the shallow part of the models (see paragraph n. 2.5).

2.4 Laboratory measurements of the physical parameters of rocks

This study concerns laboratory measurements of seismic velocity in rock samples stressed at high pressure [5]. Ultrasonic laboratory measurements of seismic compression velocities (Vp) have been carried out for volcanic rocks from Etna region as well as for carbonates belonging to its basement. The experimental set-up for the pressure tests consisted of a digital oscilloscope and a pulse generator. First results show that Vp is affected by microstructure, mineralogy, and anisotropy of the investigated rocks. This study improves the amount of seismic wave velocity data measured in different materials, and provides new significant elements to the design and realization of a pre-alert system, through the comparison with signals from an under-water seismometer [6] transmitted via optical fibres.

2.5 Strong ground motion evaluation for different earthquake scenarios

Computation of the strong ground motion for the urban area of Catania has been carried out for different earthquake scenarios. The results were that a hypothetical scenario with a very local earthquake of magnitude ca. 5.5-6 appears to be the most critical one in the northern part of the city of Catania. This is somewhat surprising since the earthquake of 11 January 1693 is the largest one occurred in the region, and one commonly refers to it for hazard evaluation in Catania. A second-level scenario earthquake will be analysed in the third year of the research activity. However the 1693 earthquake is the first level scenario earthquake and it is the most severe earthquake for the central and the southern part of the city of Catania.

2.6 Local response and site effect evaluation

The site response of seven sites located in Catania has been evaluated through both 1-D and 2-D numerical simulations. The main goals of the study were: 1) to analyse how the wave-field is modified during its passage through the sequence
of the shallowest soil layers of a 2-D model, 2) to compare the effect of different definitions of “bedrock seismic input” on 1-D simulations, and 3) to evaluate the range of applicability of non-linear 1-D and linear 2-D approaches [7] in the case of strong ground motion.

Figure 1: Base map of the study area, showing the transect position and the sites location. The blue circle shows the position assumed for the reference earthquake of January, 11, 1693.

The 2-D spectral element method was used for the 2-D simulations. The investigated sites are located along transect T01 (Figure 1), the same which was used for the simulations of the destructive 1693 Catania earthquake during the first Catania project [8; 9]. The shallow structure of the model has been defined in detail at the seven study sites using all the available geotechnical data. Seismograms have been computed (Figure 2) at several depths, starting from the ground surface, in order to study the wave field propagation through about one hundred meter of surface soils. The reference earthquake is the January 11, 1693 M=7.0 Eastern Sicily event. The source is located along the northern segment of the Ibleo-Maltese fault and has pure normal mechanism. The extended source, defined through five elementary point sources, reproduces the rupture propagation along the fault segment and the heterogeneous distribution of the seismic moment along the fault in an approximate way. Different source ruptures have been evaluated.

The 1-D method, which is commonly used in engineering practice, takes into account the detailed shear waves soil profile of surface layers, including soil non-linearity. The seismic response at the ground surface has been evaluated defining the input motion through both a conventional approach (i.e., scaled recorded accelerograms at bedrock) and the synthetic accelerograms given by the 2-D code at a given depth.
The study shows that the seismic input provided by the 2-D simulations, which reaches the value of about 0.5 g, is considerably larger than the conventional one, and it has the effect of producing large non-linear behaviour within the soil column. Hence, 1-D non-linear modelling has to be preferred to the 2-D linear one in the epicentre area, whenever the soil structure can be approximated by a 1-D model. Finally, the 1-D non-linear soil response has been evaluated for 108 geo-settled sites where are located the ecclesiastical buildings [10].

Figure 2: Site response at sites n. 1, 3, and 5 computed for a seismic moment distribution characterised by one dominant asperity. VS profile (left), acceleration time histories of the radial component (centre), and spectral ratios between the accelerations computed at different depths (i.e., receivers 1 (red colour, at ground surface), 3 (green, at z » 35 m) and 5 (blue, at z » 70 m), respectively) and receiver 6, located within the bedrock at depth of about 170 m.

3 Vulnerability of physical environment, road infrastructures and urban system

3.1 GIS data management

All the data available from the previous Catania Project [8], and all the data available for the research activity of the research Project were collected and assembled in a GIS. The database of borings was upgraded up to 910 boreholes including new borings and new soil profiles. The level of the available information were upgraded in homogenous and corrected soil profiles and by correlation between soil profile and shear waves velocity. The geological map of the city of Catania was geo-settled, as well as the geophysical map of shear
waves velocity was geo-settled and upgraded. All the potential landslides areas were geo-settled, as well as the liquefaction potential areas. The GIS was made directly accessible by ArcView user [11]. A CD with all data, becoming available so far, can be distributed to individual group of users at the end of the third year of research.

3.2 In situ measurements: test sites

For upgrading the database available and the empirical correlations between the shear waves velocity and geotechnical soil properties, direct in-situ measurements of shear waves velocity were made at specific test sites. Following the site characterisation made by the previous Catania Research Project, in addition to the test site of Via Stellata [12], the two new test sites of Piazza Palestro and San Nicola alla Rena Church were analysed. Borings, SPT tests, Down-Hole tests and laboratory tests including resonant column tests and cyclic loading torsional shear tests were performed to detect soil non-linearity. The specific laboratory test for detecting soil non-linearity behaviour is a key point for evaluating local response and site effects, because as stated in paragraph 2.6, 1-D non-linear soil response is preferable to 2-D linear soil response in the flat epicenter area. The correct evaluation of local soil response is in turn a key point for the microzonation study reported in the following paragraph.

3.3 Microzonation

The microzonation of empirical prediction of ground shaking [13], available from the previous Catania Project could be considered as microzonation of grade 2, according to the Manual for Zonation on Seismic Geotechnical Hazards [14], because this is based on local ground conditions and attenuation relations [15; 16], without evaluating local soil response. An alternative microzonation of grade 2 was performed by Grasso and Maugeri [17], based on the Spudich et al. [18] attenuation relation. A grade 3 microzonation has been carried out, based on the response analysis performed for the soil profiles given by the about 910 boreholes available on the GIS database. The seismic response at the ground surface has been evaluated defining the input motion through both a conventional approach (i.e., scaled recorded accelerograms at bedrock) and the synthetic accelerograms given by the 2-D code at a given depth, according to paragraph 2.6. The grade 3 microzonation of the northern part of the city of Catania is reported by Grasso and Maugeri [19]. The microzonation of the whole city of Catania, in addition to ground motion, will take into account slope instability (see next paragraph) and potential liquefaction which was analysed during the first year of research.

3.4 Slope instability

To detect the slope stability hazard two new models have been developed of which one for clay slope for which soil stability is affected by strength cyclic degradation [20] and one for saturated sand slope for which soil stability is
affected by pore pressure build-up [21]. The model referred to clay slope has been applied for based displacement analysis of the Monte Po landslide in Catania (figs. 3 and 4). The model referred to the saturated sand slope has been applied to the shore line of Catania city were flow failure with lateral spreading can be expected because of liquefaction phenomena.

![Diagram](a)

![Diagram](b)

Figure 3: a) Schematic section of the Monte Po slope assumed in the analysis; b) Reduction of slope critical acceleration caused by the soil cyclic degradation.

![Diagram](c)

![Diagram](d)

Figure 4: Results of the displacement response analysis of the Monte Po slope.

### 3.5 Foundation stability

A new model for bearing capacity analysis taking into account inertial forces not only in the foundation but also in the soil, according to the suggestion of Eurocode EC8, has been developed [22]. The model has been applied to the foundation analysis of one R.C. building built in Catania with no seismic design. The analysis of foundation stability is based on the results of the test sites investigation (see paragraph 3.2). The results achieved show that the existing foundation must be improved to resist against seismic forces. The reinforcement of foundation will be considered in the Code of Practice concerning the assessment and strengthening of reinforced concrete buildings (see paragraph 4).
Soil-foundation-structure interaction has been analysed by shaking table tests for a frame of a R.C. building [23].

3.6 Retaining wall stability

A new model for analysing retaining wall stability has been developed [24] and application of the model for evaluating the factor of safety has been presented [25]. The risk analysis of road infrastructure system is related to the stability of retaining walls; in some cases in the city of Catania the retaining wall is supporting a building; the model developed takes into account different typology of surcharge applied on the backfill due to buildings, vehicles etc.

3.7 Cavities survey and database

Survey of the cavities under the Catania area and implementation of a database of detected cavities have been improved. The following cavities have been studied in detail: Casa di Sant’Agata, cavity Piazza A. Di Benedetto, cavities via Lavandaie, Pozzo Gammazita, cavity Piazza Currò, Cripta of S. Agostino Church [26]. In the city of Catania the cavities represent a high risk for foundation stability of some buildings.

3.8 Seismic road network reliability

Vulnerability of the roads have been related to vulnerability of landslides (see paragraph 3.4) and retaining walls (see paragraph 3.6). The vulnerability of bridges was investigated in the previous Catania Project [27; 28; 29]. In some cases it is very relevant the functionality of road network during and after an earthquake. As regards road infrastructure system, an original methodology for the risk analysis of the functionality of the urban infrastructures system during earthquakes has been developed and applied to the risk analysis of a specific urban area of Catania [30;31; 32].

3.9 Urban system vulnerability

The seismic vulnerability of the urban system of Catania is considered as a set of relationships between built areas and void areas for connection. 1,346 void space are considered, consisting of streets and squares. The prevailing causes for the exposure of the population (in each empty urban space) caused by the activities practised in the built areas have been defined. To this aim the main typologies of economic activities have been determined and specific forms of evaluation have been defined. The points are assigned to the five categories of judgement (year of construction of the manufacture were the activity is located, number of consumers/hour, function of the road, presence of analogous activities within the radius of 300 m, general vulnerability), with maximum value of 50, which is also the index of maximum risk. As regards the evaluation of the general vulnerability of the urban framework of Catania, the following factors have been
considered: organisation of the vertical structures (the presence of the connections between orthogonal walls); nature of the vertical structures (employed materials and their conditions); position of the building; type of foundations; distribution of the resistance elements; regularity of the project; presence of appendixes or projections; state of fact and evident interventions of amelioration or maintenance carried out; lack of joints. The seismic vulnerability of urban system is linked not only with the vulnerability of buildings (see paragraph 4) but also with the functionality of road network (see paragraph 3.8) and interruption of economic activities. Also the exposition of the population due to economic activities is considered for the evaluation of the seismic risk [33].

3.10 Lifelines

Some studies were carried out in the past to assess the response of buried pipes to lateral ground movements with the aim to establish pipe failure risk. The analyses of soil-pipe interaction in slope with earthquake-induced movements is developed using the discrete element method to evaluate deformations and stresses in pipelines crossing unstable slopes.

The distribution of displacement, lateral deflection and bending moment along the pipe are calculated for the previsi on of unacceptable conditions for pipelines and to prevent seismic hazard in a risk analysis [34]. Seismic hazard assessment for pipelines crossing unstable slopes has been also performed [35].

4 Vulnerability and seismic structural improvement of buildings to prevent damage

4.1 Vulnerability of masonry ancient monuments

The vulnerability models and scenarios for the Churches have been analysed by Cavaleri et al. [36]. Concerning masonry ancient Churches, an improved surveying form with respect to the form [37] proposed insight the Catania project has been proposed. Data acquisition (by means of the previous defined form) with regard to a set of ancient monuments has been performed. The score based methodology is based on date acquirable by means of the improved form [38]. These form makes it possible to evaluate the first and second level vulnerability of churches with a nave and possibly aisles. For this purpose, two evaluation parameters have been considered, defined respectively as safety index $S_i$ and damage index $D_i$. The form has been already applied to survey and evaluate a set of 10 churches. Among these Churches, the most vulnerable one in order to carry out specific study has been selected. Further assessment of the selected monument based on diagnostic tests and numerical simulation have been made for Saint Nicola alla Rena Church [38] damaged by the moderate 1990 earthquake. The results of the case study of Saint Nicola alla Rena have been organized so that the following steps have been stressed: a) definition of a reference analytical model based on data revealed by means of the surveying forms; b) design of the vibrational test in situ, by means of numerical
simulations, to acquire the dynamic characteristics, subjecting the systems to different types of dynamic loads; c) execution of the test in situ and acquisition of the dynamic characteristics in terms of accelerations; d) development of an accurate analysis in the time and frequency domains of the acquired responses and definition of both flexural and torsional modal shapes (figure 5).

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Figure 5: Numerical model dynamically identified of the San Nicola alla Rena Church in Catania.

4.2 Vulnerability of reinforced concrete buildings

Cosenza et al. [39] have been carried out the seismic assessment of two reinforced concrete buildings, representative of the most common r.c. typologies of the Catania city. The studied outlined a high vulnerability for the buildings: the collapse will occur for PGA values ranging between 0.10 and 0.15 g, whereas the expected PGA values are about equal to 0.3 – 0.4g, as stated by the previous Catania Project [13]. However, as outlined by Cosenza et al. [40], the studies carried out by different research groups [41; 42] showed that the use of different models result inconsistent even if concerning the same building. A validation is then needed to eliminate the discrepancy of the obtained results with regard to pushover simulation carried out on the same building. Numerical
assessment will be made on selected buildings implemented in a “Data Bank” tailored to Reinforced Concrete building data acquisition and management.

Vulnerability of R.C. buildings can be made by simplified procedures based on vulnerability score and simplified mechanical procedures or by detailed analysis based on resistance evaluation of the buildings against earthquakes. The considered building has been built in the years ’70 and never completed. Because of this a degradation phenomena caused a decreasing of strength to be evaluated. With this aim the procedure developed published in the National literature [43] and in the international one [44], has been applied. The results obtained show a high degree of vulnerability for the expected seismicity at the site. The evaluation of seismic resistance and vulnerability of existing buildings, as well as to the problems of seismic improvement of vulnerable buildings, are strictly correlated because preliminary must be evaluated the strength against earthquake and the consequent vulnerability of it; successively must be evaluated the improvement of the same buildings to resist to the earthquake (see next paragraph 4.3).

4.3 Strengthening of reinforced concrete buildings

Among the various systems for structural improvement for the considered building (see previous paragraph 4.2), the base seismic isolation was particularly suitable. However even with the base isolation the building showed some vulnerability and because of that a structural strengthening was needed. To this aim some shear walls were modelled and designed [45]. The seismic structural improvement was then consisting of base isolation and of structural strengthening. The study shows an interesting behaviour predicted by the model. Because of the structural strengthening due to shear walls, the vibration periods of the building became less, and then bigger seismic forces were acting on the building. So the increasing of the resistance due to the shear walls was not enough to compensate the increasing of actions. However, because of base isolation, the vibration periods of the building became higher as well as the damping; consequently the seismic action was decreasing and the building behaves as linear system. The results obtained have been reported by Caliò and Marletta [46] and Caliò et al. [47]

For the assessment and strengthening of reinforced concrete buildings, a code of practice will be developed and disseminated among professional engineering. The Code of Practice [48] concerns inspection, assessment and strengthening provisions. The inspection provisions concern all the activities needed to define building geometry and mechanical properties of concrete and reinforcement. Among the recently proposed seismic assessment guidelines the ATC 40 proposal seems to be better tailored for the Italian scenario, safe that some adjustment is needed. So that the Code of Practice is organized as the ATC 40 “Seismic evaluation and retrofit of concrete buildings” in two volumes: the first one describes the proposed methodology, the second one contains: 1) one typological case study; 2) a real case that include a cost effectiveness study [46]; 3) supplemental information on foundation effects (see paragraph 2.5).
4.4 The intelligent Data Bank

The proposed intelligent Data Bank [48] is an integrated software expert system [49] for the seismic vulnerability evaluation. The system provides an expert interface and a vulnerability analyzer. The expert interface assists the surveyor in the geometric and mechanical description of reinforced concrete buildings; the vulnerability analyzers will assist the engineers in the planning and estimation of the interventions for seismic risk management. Organism data are collected from on-site surveys, while the system provides an expert interface to assist the surveyor in the geometric and mechanical description of the building. Data are subsequently integrated in a C.A.D. (Computer Aided Design) system interface and then analyzed on the basis of “intelligent” risk estimation models, in order to compute the organism seismic risk. Finally, the “local” risk analysis could be connected to the “global” analysis of the city through a G.I.S. (Geographical Information System) interface.

The proposed “Data Base Driven System” will help the technician in applying the methodology proposed in the “Code of Practice” so that, on the basis of a Rule Based System, the Performance Objectives will be defined. Further on the system will drive, if needed, the engineer in the selection of the best retrofitting strategy by means of heuristic rules and comparative numerical simulation. Further the system allows large-scale vulnerability evaluation by means of simplified mechanical model as well as vulnerability score-based assessment. The simplified mechanical-based module evaluates the expected damage by means of a simplified pushover analysis performed with an n-DOF stick model.

5 Conclusions

The earthquake of M=7 for simulation of the January 11, 1693 was chosen as scenario earthquake. Detailed analyses have been carried out for better evaluation of the characteristics of the scenario earthquake and for the evaluation of uncertainty linked with the model used. With this aim different distance, ranging between 15-25 Km, between the seismic source and the city of Catania have been considered. Different source modelling has been used. Using the same distance of the source (15 km) and the same methodology (SPEM), different results have been achieved by using a uniform moment distribution or models with one or two asperities. An innovative approach is related to the laboratory measurements of seismic velocity in rock samples stressed at high pressure, with relation to the attenuation laws. Microtremor measurements in some test areas show significantly soil amplification due to geological nature of the soil. Because of this a geological model of the city of Catania, was considered. Site response has been evaluated with 2-D and 1-D model. An innovative approach was that of evaluating the synthetic accelerograms not only at the surface but also at the bedrock. Using the last as input, PGA up to 0.5g was evaluated. As far as concern the vulnerability of physical environment, in addition to the test site of via Stellata, the two test sites of Piazza Palestro and of the San Nicola alla Rena Church have been studied. The site response with 1-D models is highly
influenced by soil non-linearity. From results so far obtained, the 1-D non-linear model is preferable to 2-D linear model in the epicentral and flat area. As far as concern the vulnerability of physical environment due to landslides, two innovative models have been developed: one for clay slope and one for saturated sand slope. The models have been applied to the landslide and liquefaction hazard evaluation in the city of Catania. Among the element of vulnerability of physical environment, the peculiar presence of cavity in the city of Catania has been also taken into account. An innovative model has been developed for foundation stability evaluation including soil inertia effect, according to the suggestions of the Eurocode EC8. An original model has been developed for the evaluation of the seismic stability of the earth retaining walls, which is a relevant topic for the physical vulnerability of the road infrastructure system. An innovative procedure has been developed also for the evaluation of the functionality of the road system during and after an earthquake. An innovative aspect is represented by the evaluation of the seismic vulnerability of the urban system, by the analysis of the vulnerability of urban building aggregates and the analysis of the number of population exposed to the seismic risk. An innovative procedure has been used for the numerical model dynamically identified of the Church S. Nicolò l’Arena and also for the vulnerability and strength analysis of an existing building to resist to an earthquake. For this building an innovative structural improvement of building to prevent damage has been proposed.

In conclusion the project has been developed methodology aspects and innovative models related to: site effect evaluation, microzonation, vulnerability of physical environment evaluation (landslides, liquefaction, cavities), vulnerability and strengthening of test buildings, development of the code of practice for R.C. buildings and the intelligent system for the assessment of the vulnerability.

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References


