Detailed Scenarios and Actions for Seismic Prevention of Damage in the Urban Area of Catania

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Introduction

The main research activities of the Project 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; 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 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.

The Research Unit No. 8 was retired because of the temporary reduction of financial support, but the original goals of the Project did not change, because its activity is carried out by R.U. No. 4 and R.U. No. 9.

Characterisation of the expected ground motion and site effects

The characterisation of the expected ground motion and site effects are the main topic of research activity of the R.U. No. 4 (Scientific Responsible: G. Lombardo), R.U. No. 5 (Scientific Responsible: G. Immè), R.U. No. 9 (Scientific Responsible: E. Priolo) and R.U. No. 1, this one limited to site effects evaluation only (Scientific Responsible: M. Maugeri).

The research activity of the second year of the Project for the R.U. No. 4 can be summarised as following:

- simulations of the strong ground motion caused in the area by different scenario earthquakes have been continued, and somewhat confirmed the results already published. At the same time analysis and interpretation of a set of noise measurements were performed and already published (Catalano et al., 2003);
- several new microtremor measurements have been performed in test sites located both in Catania downtown and in areas interested by tectonic structures. Moreover, noise measurements in both public historical and private buildings as well as in sites located nearby cavities, have been performed;
- a detailed geological survey of part of the historical downtown was carried out, therefore improving the previous geological map of Catania (Monaco et al., 2003).

The research activity for the R.U. No. 5 are related to laboratory measurements of seismic velocity in rock samples stressed at high pressure.

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 strongly affected by the different microstructure and mineralogy of the investigated rocks. Influence of Vp from the rock anisotropy are also evidenced.

The interest on this study for the project aims, is related to the information from the measurements of the seismic wave velocity in different material and to the comparison with signals from an under-water seismometer (Beranzoli and Favali, 2003), transmitted via optical fibres, with the aim to project and realise a pre-alert system.

The research activity for the R.U. No. 9 can be summarised as following: a) simulation of earthquakes (Laurenzano and Priolo, 2003) and local response in Catania and neighbouring area (Priolo et al., 2003); b) inversion of updated intensity data-base, for an improved source characterisation (Pettenati et al., 2003).

In the item a) has been simulated numerically the December 13, 1990 M = 5.8 Eastern Sicily earthquake, the only recorded earthquake in the given area. To evaluate site response simulation of the scenario 1693 M≅7 earthquake at seven sites located in Catania has been made, using a 2-D method with the aim of analysing how the wave-field is modified during its passage through the sequence of shallowest soil layers. The results of these simulations have also been used by U.R. 1 in Task A to estimate the range of applicability of a 1-D method (Grasso et al., 2003).

The numerical simulations have been performed by the 2-D Chebyshev spectral element method. The investigated sites are located along transept t_{01}, the same which was used for the simulations of the destructive 1693 Catania earthquake during the first Catania project (GNDT, 1999; Priolo, 1999). In this study, 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 at several depths, starting from the ground surface, in order to study the wave filed propagation through about one hundreds meters of surface soils. The source is located along the northern segment of the Ibleo-Maltese fault and has pure normal mechanism (Figure 1). The source is defined through 5 point elementary sources, which are used to reproduce the rupture propagation along the fault segment and the heterogeneous distribution of the seismic moment along the fault in an approximate way. Four different types of seismic moment distribution and release have been simulated for the source.
As an example of the results obtained, Figure 2 compares each other the responses estimated at three different sites (i.e., sites n. 1, 3, and 5, respectively). The figure shows the site 1-D structures, computed waveforms, and spectral ratios between the accelerations at selected depth and the bottom receiver, which is located within the bedrock.
In the item b), related to the inversion of updated intensity data-base, for an improved source characterisation, automatically are inverted various macroseismic intensity data sets - among which that by Barbano and Rigano (2001) - of the two destructive earthquakes of 1693 in SE Sicily, and retrieved the principal geometric and kinematics source parameters of the events. The Jan. 9 and Jan. 11, 1693 sources - constrained by our inversions - form a NNE oriented segmented fault, approximately 60 km long; then, according to the different intensity data sets used, the retrieved 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 Jan. 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.
The research activity of the second year of the Project for the R.U. No. 1, related to site effect evaluation, was evaluated for the 108 geo-settled ecclesiastical buildings. In order to identify the amplification effects due to the site, the soil response has been evaluated employing a 1-D dynamic hysteretic simplified soil response model (Grasso and Maugeri, 2003a).

Vulnerability of physical environment, road infrastructures and urban system

The vulnerability of physical environment, road infrastructures and urban system are the main topic of research activity of the R.U. No. 1 (Scientific Responsible: M. Maugeri) and R.U. No. 3 (Scientific Responsible: G. Dato).
The research activity for the R.U. No. 1 can be summarised as following.
The GIS technique (Grasso and Maugeri, 2003b) was employed for zoning the vulnerability of physical environment of the city of Catania. Following the site characterisation made by the previous Catania Research Project, in addition to the test sites of Via Stellata, the two new test sites of Piazza Palestro and San Nicola alla Rena Church were analysed. Borings, in situ tests and laboratory tests including resonant column tests and cyclic loading torsional shear tests were performed to detect soil non-linearity. Two new test sites are now under way, one of which located in correspondence of a building analysed in one case in the previous Catania Project

and in the other case located in correspondence of a building analysed in this Project.
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 (Biondi and Maugeri, 2003) and one for saturated sand slope for which soil stability is affected by pore pressure build-up (Biondi et al., 2002). 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.
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 (Maugeri and Novità, 2003). The model has been applied to the foundation analysis of one R.C. building built in Catania with no seismic design. Soil structure interaction has been analysed by shaking table tests and application to a frame of the R.C. buildings analysed in the following section is undergoing.
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 (Bonaccorso and Lo Giudice, 2003). 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 (Cafiso et al., 2003). The risk analysis of road infrastructure system is also related to the stability of retaining walls. A new model for analysing retaining wall stability has been developed (Caltabiano et al., 2003a) and application of the model for evaluating the factor of safety has been presented (Caltabiano et al., 2003b).
The research activity of the second year of the Project for the R.U. No. 3 can be summarised in the following.
The seismic vulnerability of the urban framework 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. Have been defined the prevailing causes for the exposure of the population (in each empty urban space) caused by the activities practised in the built areas. To this aim the main typologies of economic activities have been determined and specific forms of evaluation have been defined. The points 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), they have the superior limit of 50, that is also 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; unification of buildings.

Vulnerability and seismic structural improvement of buildings to prevent damage

The vulnerability and seismic structural improvement of buildings to prevent damage are the main topic of research activity of the RU. No. 7 (Scientific Responsible: G. Zingone), R.U. No. 2 (Scientific Responsible: G. Oliveto) and R.U. No. 6 (Scientific Responsible: F. Braga).

The research activity of the second year of the Project for the R.U. No. 7 has been dedicated to the definition of the numerical model dynamically identified of the Church S. Nicolò l'Arena. The Church, is considered as a significant specimen of monumental works of the historical centre of Catania. This monument has been selected through the classification in terms of seismic vulnerability, developed by forms deliberately elaborated. For this aim the results obtained during the first stage of The Catania Project were useful.

The acquisition of the dynamic characteristics, in terms of acceleration, have been acquired through a vibrational test in situ. Has been adopted the modern technique of dynamic identification (fig. 5a), which is useful to calibrate the reference model with the real one, in terms of frequencies and modal shapes. The analysis of the signals in the time and frequencies domains allowed us to acquire useful information related both to the flexural and torsional stiffness values and to the damage state of the structural elements considered. The analytical model dynamically identified has been utilised for the determination of the torsional (fig. 5b) and flexural (fig. 5c) modal shapes that have shown interesting aspect regarding: the first and second level global vulnerability and the seismic resistance of the various structural elements; the appearance of probable collapse mechanism of significant macro-element of the structural system.

The research activity of the R.U. No. 2 has been devoted to the problems of the evaluation of seismic resistance and vulnerability of existing buildings, as well as to the problems of seismic improvement of vulnerable buildings. The two problems can be considered 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.

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 in the first year of the research activity, published in the National literature (Oliveto, 2001) and in the international one (Oliveto, 2002), has been applied. The results obtained show a high degree of vulnerability for the expected seismicity at the site. Among the various systems for structural improvement for the considered building, 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 (Marletta, 2003). 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 presented to the Workshop on the second year of activity of the Project (Caliò and Marletta, 2003; Caliò et al., 2003); some topics have been included on the Ph. D. thesis which will be discussed in the near future (Marletta, 2003).

The research activity of the second year of the Project for the R.U. No. 6 is related to the development and implementation of two products: a Code of Practice concerning the Assessment and Strengthening of Reinforced Concrete Buildings (Braga et al., 2003) and an intelligent system for assessing the vulnerability (Padula, 2003).

The Code of Practice concerns assessment and strengthening provisions. 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. The ATC 40 "Seismic evaluation and retrofit of concrete buildings" had been chosen for its unique completeness, at least as far as practice and the general procedure are concerned, it must be recognised that the methods therein implemented need some improvement and to be re-tailored for the Catania scenario.

The proposed Data Bank is an integrated software expert system for the seismic vulnerability evaluation. The system provides an expert interface and a vulnerability analyser. The expert interface assists the surveyor in the geometric and mechanical description of reinforced concrete buildings; the vulnerability analysers 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 analysed on the basis of "intelligent" risk estimation models, in order to compute the organism seismic risk. Finally, the "local" risk analysis is connected to the "global" analysis (city or province) through a G.I.S. (Geographical Information System) interface.

Conclusions

The previous Catania Project has proposed an earthquake of M=7 for simulation of the January 11, 1693 scenario earthquake. The scenario earthquake is characterised by the peak ground acceleration (PGA) ranging between 0.15 and 0.35g. 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 are considered. Different source modelling has been used by R.U. No. 4 and R.U. No. 9. 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 (R.U. No. 9). An innovative approach is related to the laboratory measurements of seismic velocity in rock samples stressed at high pressure (R.U. No. 5), with relation to the attenuation laws. Microtremor measurements in some test areas show significantly soil amplification due to geological nature of the soil (R.U. No. 4). Because of this a

geological model of the city of Catania, practically ignored in the previous Project, was considered (R.U. No. 4). 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, considerable bigger than that evaluated by the previous Project.
As far as concern the vulnerability of physical environment (R.U. No. 1), in addition to the test site of via Stellata analysed in the previous Project, the two test sites of Piazza Palestro and of the San Nicola alla Rena Church have been studied. The analysis of other two test sites in correspondence of a structure studied by the previous Project and a structure studied in this Project is undergoing. The site response with 1-D models 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 presented to international revue and conferences and 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 (R.U. No. 1). 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 (R.U. No. 1). 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 (R.U. No. 3).
An innovative procedure has been used for the numerical model dynamically identified of the Church S. Nicolò l'Arena (R.U. No. 7) 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 (R.U. No. 2).
As far as concern the Code of Practice for the assessment and strengthening of reinforced concrete buildings and the intelligent system for assessing the vulnerability, about 65% of the work has been already done.
The results achieved in the second year of research have been presented and discussed during the Workshop "Detailed Scenarios and Actions for Seismic Prevention of Damage in the Urban Area of Catania", held in Catania on January 09-10, 2003, to which local engineers and researchers of other Projects have been attended. Because no temporary personnel have been assigned to the Project, as documented by the Workshop, the results have been achieved with the help of Ph. D. students G. Biondi, A. Condorelli, S. Grasso, M. Marletta, for which the topic of Ph. D. dissertation has been chosen in the framework of the topics of interest of the Project. The above mentioned students have been included in the original Project as components of R.U. No. 1 and R.U. No.2. By the way for the second and third year of research activity have been destined to the Project one temporary researcher (M.R.

Massimino) and one post Ph. D. student (D. Novità) financed by the University of Catania. In conclusion the Project has been achieved the results scheduled for the second year of activity. In particular all methodology aspects and innovative models have been already developed. in the third year of research activity more application of methodology and innovative models are needed in test areas, where all the R.U. will develop application related to: site effect evaluation, microzonation, vulnerability of physical environment evaluation (landslides, liquefaction, cavities), vulnerability and strengthening of test buildings. The code of practice for R.C. buildings and the intelligent system for the assessment of the vulnerability will be completed.

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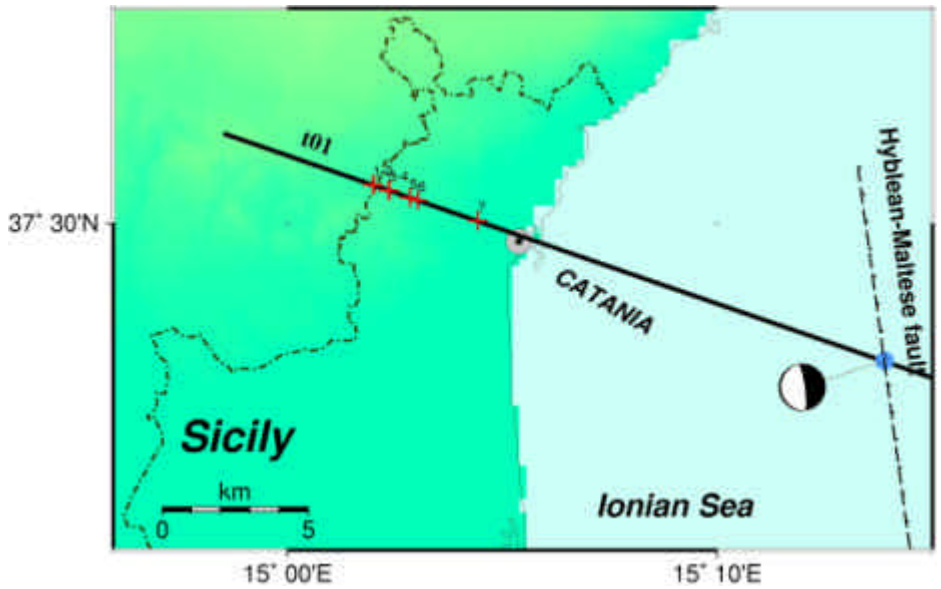


Figure 1. Base map of the study area, showing the transept position and the sites location. The blue circle shows the position assumed for the reference earthquake of January, 11, 1693.

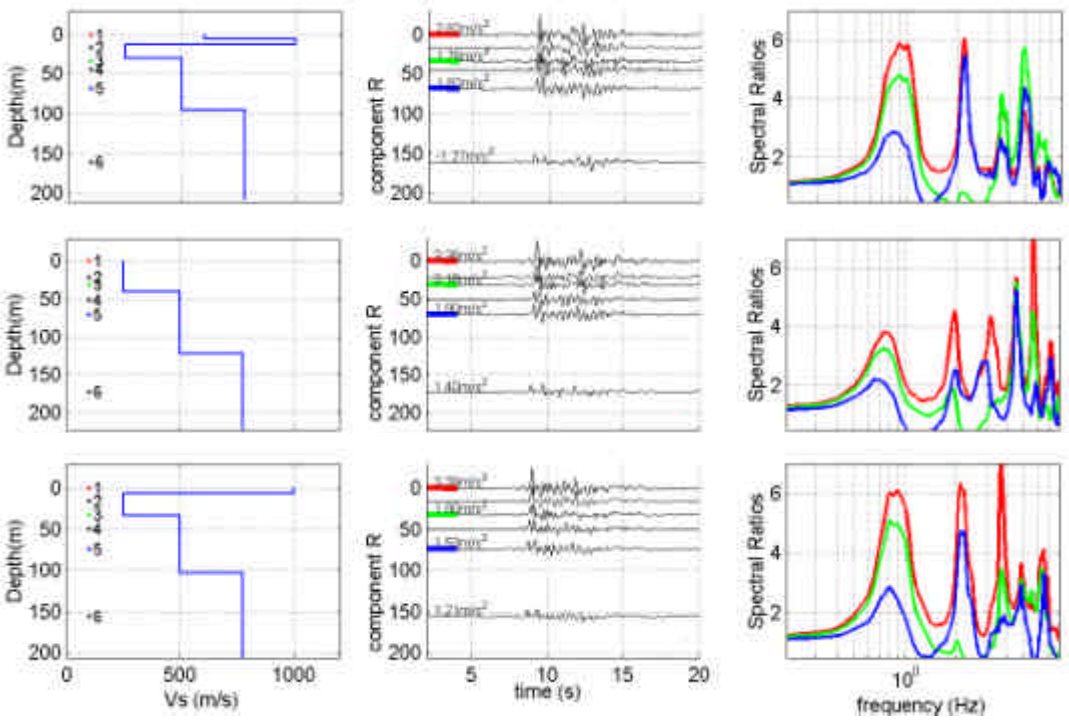


Figure 2. Site response at sites n. 1, 3, and 5 computed for a seismic moment distribution characterised by one dominant asperity. V_S profile (left), acceleration time histories of the radial component (centre), and spectral ratios between the accelerations computed at different depths (i.e., receivers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

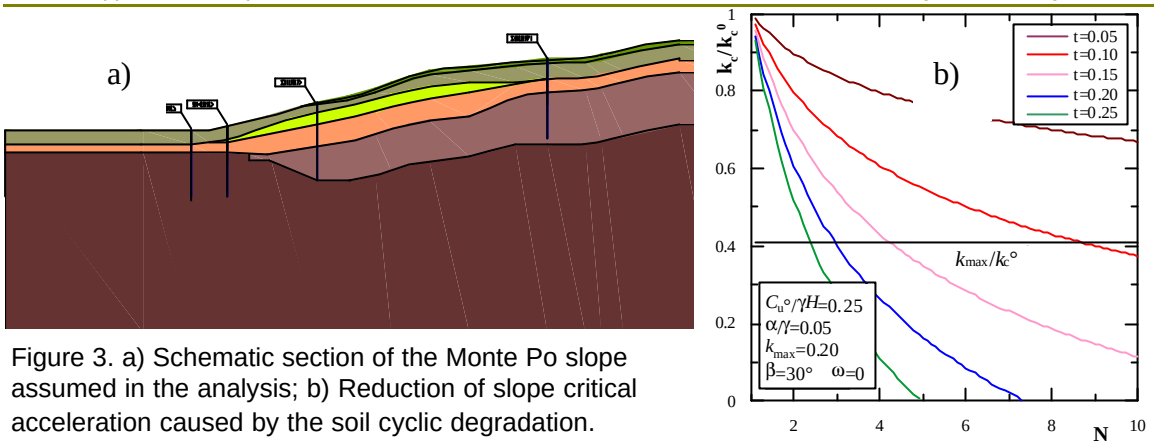


Figure 3. a) Schematic section of the Monte Po slope assumed in the analysis; b) Reduction of slope critical acceleration caused by the soil cyclic degradation.

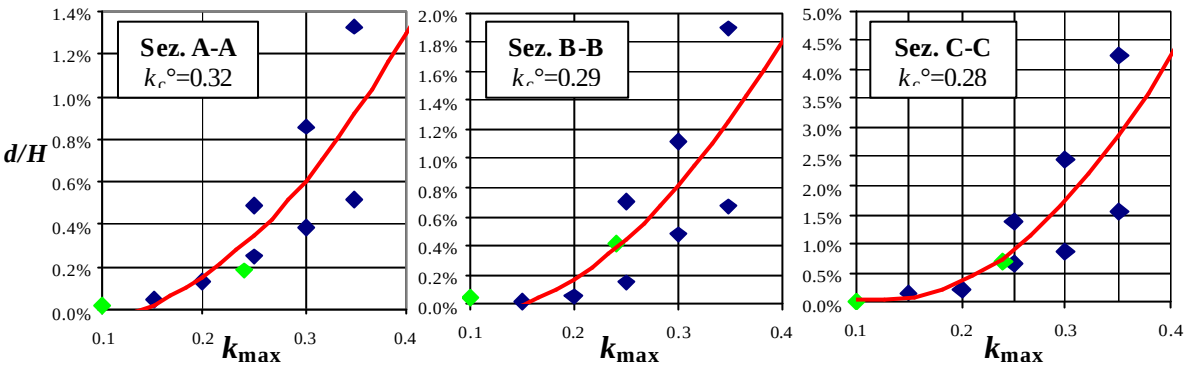
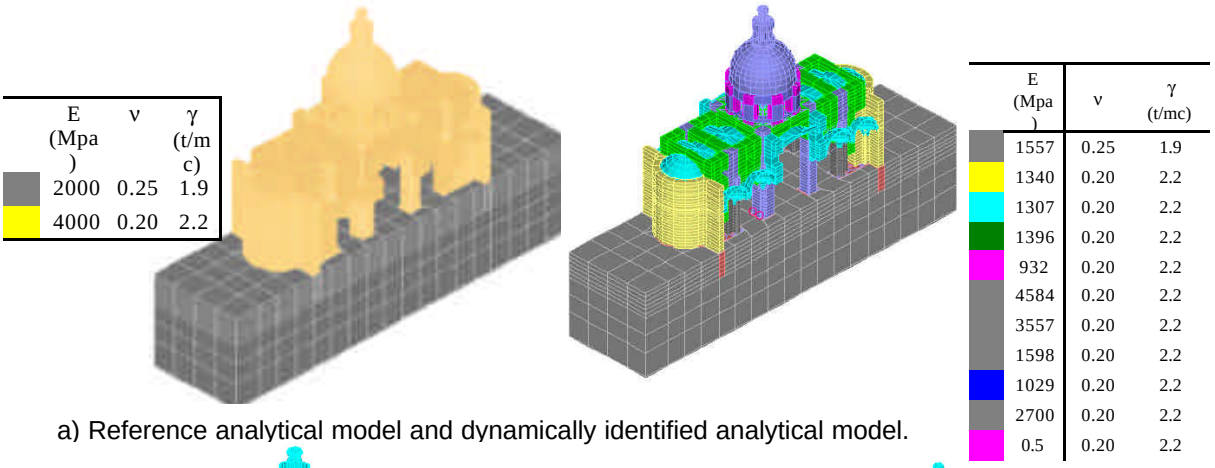
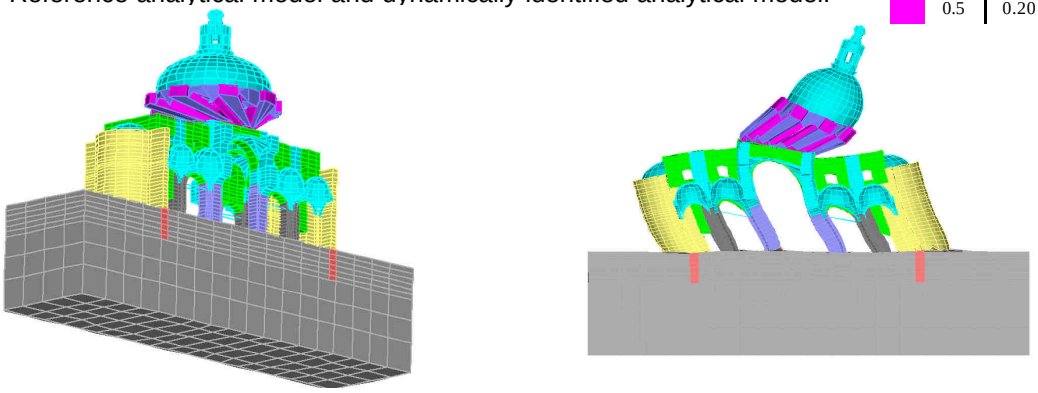


Figure 4. Results of the displacement response analysis of the Monte Po slope.



a) Reference analytical model and dynamically identified analytical model.



b) Torsional modal shape. c) Flexural modal shape.

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