TRAIANO – Project for Assessment and Reduction of Vulnerability of Urban Areas

Coordinator: Prof. Edoardo Cosenza

Introduction

The project goal is a multidisciplinary and innovative way of studying the problem of vulnerability assessment of urban areas, in order to integrate all geophysics, geological, geotechnical, structural and urbanistic informations that can contribute to the definition of damage scenarios.

The final scope of the project is make available to local administrations a territorial information platform supporting the different stages of management of seismic vulnerability; this goal is pursued through the following objectives:

- Definition of the expected seismic input, based on potential active seismic sources models, and models for regional and local propagation; information for scenario analysis are made available, and three relevantly different scenarios are considered.
- Definition of local site effects, employing different methodologies, both numerical and instrumental, and determination of microzonation maps with reliability level depending on the quality and richness of the database.
- Built environment classification, distinguishing classes with structural homogeneity, and definition of vulnerability maps based both on semi-quantitative methods for building classes and on detailed avant-garde analyses for r.c., masonry and archeologic/monumental constructions.
- Innovative methodologies for vulnerability reduction based on soil treatment techniques or structural reinforcement with the application of advanced composites.
- Construction of Geographic Information System (GIS) integrated with all available databases from local administrations and with the implementation of simplified algorithms for the models built in the project.

In order to test the procedures and methodologies implemented in the project, it was decided to refer to the town of Benevento. This place was chosen because it is sited in a highly seismogenetic area and due to its morphologic and stratigraphic characteristics, as well as for the presence of historical and archeological relevant buildings.

Project activities have been split among different research units (RU) and are organised in 8 tasks (subprojects), which are briefly described in the following paragraphs, evidencing the foreseen objectives and those already fulfilled (tasks 1 and 8 are examined altogether because the same RU are concerned and they are strictly linked to the project development).

Integration among the different tasks activities is guaranteed thanks to the common objective of creating a GIS platform containing the different databases and suitable relational algorithms evaluating the urban vulnerability.

Besides, to provide an adequate information exchange and to co-ordinate the aims of the different RU working on the project, meetings of whole Units and among different

subgroups are periodically organised, according to the intersections of each task's objectives [G^2S (geophysicists, geotecnicists, structural engineers); G^3 (geologists, geophysicists, geotecnicists), GU (geologists, urbanists), G^2 (geotecnicists, geophysicists), S^3 (structural engineers for r.c., masonry and monuments buildings).

Task 1: Reference mapping
Task 8: Territorial information system for risk management
In charge: R. Papa

Foreseen objectives in three year time
First year (Task 1)

- O1/1 Definition of digital base mapping
- O1/2 Collection of data concerning the built environment disposable from Public administrations
- O1/3 Link to town databases
- O1/4 Definition of possible methodologies for speed survey

Third year (Task 8)

- O8/1 GIS construction (implementation)
- O8/2 Link to databases and town SIT
- O8/3 Representation of foreseen damage scenarios

Achieved objectives
All the first year objectives are fulfilled. Regarding O1/1 the digital mapping of Benevento town was collected and transformed into DWG geographic assigned files. Moreover, Zevi-Rossi (1980) local plans have been collected, which were useful to enrich the informations and data on built environment characteristics regarding the urban areas chosen for the project operational activities. The acquired data served also to the definition of O1/2, regarding building data collection; for this objective a territorial subdivision corresponding to urban census parcels is considered, and relative data from '91 ISTAT census were collected. Starting from these data, and on the base of aggregation levels at a greater scale than the single building, it was possible to evaluate construction periods and other important characteristics of the built environment. Regarding O1/3 useful contacts with C.E.D. of Benevento town administration were instituted, basic for the integration between the Traiano project geographical database in progress and the Territorial Information System (SIT) built by local administrations.
The objective concerning possible methodologies for speed screening and definition of GIS implementation standards (O1/4) was fulfilled thanks to the constant interaction and readjustments during work phases and among different RUs. Although no specific objectives for the second year were foreseen, the RU kept on working at the construction of a GIS platform and started to fill the different data layers contained into GIS. Moreover historical seismic damage was investigated, and researches are going on investigating possible sources of information on this topic. As regards task 8 objectives, O8/1 is about to be fulfilled, while other objectives deal with conclusive project stages.

Results
Design, realization and filling of the information system can be considered the main result; this platform represents simultaneously a supporting instrument for research activity, the environment for damage scenarios development and the main product that can be offered to town managers. The customisation of GIS, for a non expert use, will represent the last effort of RU within the project. A sample of the GIS application is currently (march 2003) available on CD for Referees.

Description of the activities
The structure of GIS data layers has been defined, which – depending on different considered subjects and given analysis scales - will form the graphic link for the exact geographic assignment of data and will make it possible to compare informations about different topological layers, through spatial analysis (select by theme) instruments.
This will lead, in the last year, to define the procedures to compare the data regarding various subjects and the damage analysis for the forecast scenarios.
The topological layers (TL) have been defined and started filling the GIS with basic data layers (fig. 1.1) concerning data from the RUs working on task 4 (punctual TL about the position of drills), 5 (punctual TL about the position of seismic data recording sites), 6 (poligonal TL about the buildings) and 8 (poligonal TL about socio-urbanistic data).
Finally, a CD-Rom, showing the current GIS structure and general functions, is under construction.

Task 2: Definition of expected input In charge: G. Iannaccone

Foreseen objectives in three year time
- O2/1 Definition and characterization of active seismic zones
- O2/2 Simulation of accelerometric radiation
- O2/3 Sannio area 3D velocity model
- O2/4 PGA acceleration maps, response spectra
- O2/5 Synthetic accelerograms
- O2/6 GIS implementation through data from Benevento

Achieved objectives
The seismic sources for the 1688, 1962, 1930 earthquakes have been defined and characterised; acceleration maps for 1688 (fig. 2.1) and 1930 earthquakes were created.
A bi-dimensional velocity model for the propagation of P waves at a regional scale has been implemented and the accelerometric radiation from the assumed fault mechanism of the 1688 event was simulated.

Results
Comparing the PGA values calculated by simulation and the existing attenuation laws, it was pointed out that attenuation for the calculated PGA values is slightly larger than expected according to empirical relations (fig. 2.2). This effect is partially

due to the used methodology, considering only direct S waves and not surface waves.
Normalised pseudo-acceleration spectra for the hundred considered nucleation events were calculated for the site of Benevento.
Spectral shape is consistent with EC8 spectrum, average amplitude values perfectly agree for periods greater than 0.8 sec., while they are a bit underestimated for higher frequencies.

Description of the activities
Source parametres for 1688, 1930 and 1962 earthquakes have been defined.
In particular, for the 1688 event, a detailed study has been carried out, based upon geological and seismotectonic features and damage distribution, which made it possible to reliably assume the position and dimension of the fault causing the earthquake.
The spatial distribution of calculated acceleration values were compared with those expected according to empirical relations.
In particular, the attenuation curves proposed by Sabetta and Pugliese (1987) and Spudich et alii (SEA 99) were considered.
In addition to the classical Sabetta-Pugliese, also the SEA 99 relation was used, because it was obtained from a selection of direct fault mechanism events.

Task 3: Geological characterisation of the sample area
In charge: T. S. Pescatore

Foreseen objectives in three year time
- O3/1 Geological data base acquisition and organisation and GIS parameters definition
- O3/2 Preliminary study for digital mapping
- O3/3 Detailed geological survey
- O3/4 Production of litological (1:25000 scale) and litographic (1:5000 scale) chart
- O3/5 Thickness covering units chart (alluvium, eluvium colluvium, detritus, waste soil; etc.)
- O3/6 Geological-structural chart
- O3/7 Unstable soil chart
- O3/8 Underground tridimensional model
- O3/9 Hydro-geological systems chart
- O3/10 Chart of the litological types used for historical buildings construction
- O3/11 Implementation of GIS with Benevento data

Achieved objectives
The acquisition and organisation of existing database has made it possible defining and arranging the GIS parameters, also helping the preliminary study for digital mapping. New samples have been taken and a detailed geological survey (1:2.000 scale) was carried out. In particular, carrots from 7 more samples taken in Contrada Cellarulo were studied. Furthermore, a detailed survey in the town middle west area was carried out in order to better understand data from new samples.

Results

The gathered data allowed a rational reinterpretation of existing stratigraphies, based on previous drills. This way, it was possible to distinguish among different stratigraphic units and to build a coherent model for geological-structural territorial asset. Known stratigraphic data from underground and surface have been interpreted in hydrogeological terms in order to build an underground water circulation model.
Thanks to the stratigraphic, geological and archaeological study of alluvional, elluvio-colluvial and anthropoid deposits, it was possible to understand a series of volcanic, alluvial and antropica events which influenced recent morphological evolution of the area.

Description of the activities

Activities have mostly consisted of studying the existing drills and giving them a different interpretation also according to the newly acquired data.
An useful and necessary comparison with other RU using geological models was started in order to integrate each other's information and produce an underground model as reliable, coherent and relevant to the project aims as possible.
It is planned to start the geological survey of the town area in order to obtain all the stratigraphic and tectonic data. Existing drills will be analysed and compared to new ones, in order to create a stratigraphic column with relative and absolute dating and appreciate deposits facies variations in time and space.

Task 4: Geotechnical characterization and underground seismic vulnerability analysis

In charge: F. Vinale

Foreseen objectives in three year time

- O4/1 Geotechnical characterization of the whole Benevento area
- O4/2 Global seismic vulnerability analysis of the Benevento area and first level seismic zonation
- O4/3 Sample sites selection and geotechnical characterization
- O4/4 Sample sites seismic vulnerability analysis and guidelines for microzonation

Achieved objectives:

Geotechnical characterization, global seismic vulnerability analysis and first level seismic zonation of the whole Benevento area have been completed, sample sites were chosen and their geotechnical characterization was done.

Results

- GIS architecture definition based on geotechnical level.
- First level geotechnical characterization of the whole Benevento area through the collection of existing data from local administrations.
- Definition of 1D velocity model for 16 verticals in the Benevento area.
- Execution of three new drills in the sample areas (30 metres), one at the foothill of the old town centre (Porta Rufina) and two more in the Rione Libertà area,

with static and dynamic penetrometric tests, collection of ten undisturbed samples for cyclic and dynamic laboratory tests and hole conditioning for Down-hole tests execution.
- Both monodimensional and bidimensional numerical analysis evaluating RSL.
- First level zonation of the whole Benevento area.

Description of the activities

A test campaign took place and is still in progress within two sample areas, in order to determine the non linear and dissipative soil's behaviour in the first 30 metres underground.

A first analysis of the stratigraphies has shown the following results:
- Relevant presence of waste material about 9 metres high at the foothill of the historical center.
- Presence of non samplable materials (gravel and sands).
- Layer of peat about 50 cm. deep near Porta Rufina.
- Pliocenic clay substratum between 10 and 20 m deep.

Shear torsional static and dynamic tests on undisturbed samples will be done.

The characterization of waste material and peat will be pursued by laboratory tests on duly rebuilt soil. Sands and gravel shear and damping characteristics will be desumed through empirical correlation. Due correlation between site and laboratory tests will allow to extend mechanical characterisation of litological units of sample areas. Monodimensional numerical analyses along 16 verticals were performed, using calculation codes such as Shake (Shake 91, EERA, Proshake). In this first phase, Sturno accelerogram (Irpinia 1980), increased in its amplitude (PGA=0.38 g), was adopted. Results of the analyses are synthesised by response spectra at the bedrock and at surface levels for each vertical. Obtained spectra were grouped in four classes. In order to evaluate the influence of underground geometry on free-field seismic response, a bidimensional analysis (using code F.E.M. (QUAD4-M)) was carried out on a section crossing Sabato valley in the south east area of the town, where soil characterization is more detailed. Comparing results from the 1D and 2D analyses it was possible to propose a microzonation map with four microzones (fig. 4.1). In order to provide a complete microzone map, a deeper investigation is still necessary, using several verticals on a wider area so to get a more detailed and complete information as regards soils of Benvento underground.

Task 5: Recording seismic data in Benevento and validation of site effects
In charge: A. Rovelli

Foreseen objectives in three years time
- O5/1 Installation of recording stations in the area
- O5/2 Data acquisition and processing
- O5/3 Re positioning of some stations and Empirical Green's Functions
- O5/4 Validation by comparison with different methodologies
- O5/5 GIS implementation through Benevento recording data

Achieved objectives

To optimize the position of stations in the urban area, the new array configuration covers monumental and archaeological areas as well as different sectors (rioni Capodimonte e Libertà) characterized by different typologies of buildings. All the geological formations that could be potentially responsible of local amplifications (the sediment-filled valleys of Calore and Sabato rivers, and Quaternary alluvial terraces) are monitored.

Estimates of local amplifications are available for a large part of the town. Their stability has been confirmed thanks to the long Molise sequence activated by the October 31, 2002 mainshock (M_L=5.4).

Several weak events belonging to seismogenic areas of great interest for the town of Benevento were recorded. Their waveforms are collected in a catalogue of Empirical Green's Functions.

Results

Empirical estimates of site response include conventional and H/V spectral ratios, using both microtremors and earthquake data. Preliminary theoretical estimates are based on the standard 1D Thomson-Haskell method. The comparison between theory and observations is often satisfactory, but in some cases theoretical transfer functions underestimate the conventional spectral ratios. However, never theoretical values lay out of the ± 1 statistical uncertainty of observations (in red in Fig. 5.1, the blue curve is the 1D theoretical transfer function). For the reference station (ARC1), the empirical estimate is given by the H/V spectral ratio.

This comparison indicates that an approach based on a 1D modelling that accounts for the variations of soil response at different levels of strain can be an appropriate tool to assess strong ground motions on the different geological units.

Description of the activities

- Installation of seismic stations in the urban area of Benevento.
- Data acquisition and processing.

Task 6: Urban centre vulnerability

In charge: E. Cosenza

Foreseen objectives in three years time

- O6/1 Individuation of typologies for r.c., masonry and monument structures
- O6/2 Field survey activities for sample areas
- O6/3 Definition of suitable survey forms for field screening
- O6/4 Definition of simplified and sophisticated analytical models and execution of parametric analyses
- O6/5 Validation of the models through the execution of experimental test on essential structural elements: joints and columns.
- O6/6 Shaking table tests on elements of masonry structures
- O6/7 Built environment reclassification based on response models criteria
- O6/8 Analysis of significant monuments (Arco di Traiano)

- O6/9 Guidelines for classification and survey of built environment in the urban area
- O6/10 Guidelines for vulnerability assessment of monumental heritage
- O6/11 Vulnerability maps
- O6/12 GIS implementation through data from Benevento town

Achieved objectives

Typologies for r.c. and masonry buildings as well as for monuments have been established, survey forms for those typologies were determined and a field screening for nearly all the buildings in the sample areas and for the monuments was carried out.

After the definition of sophisticated analytical models, detailed analyses were performed for sample r.c. and masonry buildings and for S. Sofia church. Suitable assessment procedures for large scale vulnerability analyses, based on simplified models for r.c. and masonry buildings, were defined, and those methodologies are being implemented. The established methodology for building monuments is based instead on the typological classification of monuments and on the attribution of suitable vulnerability indexes. The aim of all the developed procedures is providing an analytical relation between seismic intensity and a probabilistic distribution of damage levels. Laboratory tests on structural elements (joints and columns of GRLD frames, and relative reinforcement details) have been pursued.

Results

A definition of r.c. building classes, on the base of morphologic/geometric parameters important for seismic behaviour and according to multilevel analysis approach, has been provided. Given the base plant shape (morphologic information), at a lower detail level classes are defined as functions of construction period, number of storeys and dimensional ranges of plant sizes (L and B for rectangular shaped plants).

A simplified mechanical model for capacity assessment of buildings is at an advanced stage of implementation. Such a model enables to generate a structural system (elements dimension and reinforcement, and relative mechanical and deformability characteristics) based on building geometry, and allows the execution of parametric analyses for vulnerability assessment of buildings classes.

A detailed push-over analysis was performed for one of the sample buildings (fig. 6.1), and stiffness, strength and ductility global system characteristics were interpreted applying the substitute structure (ATC 40) equivalent method approach.

Regarding masonry buildings, extensive studies and analyses have allowed to find a set of seismic input parameters (including duration) which are better correlated with structural damage. Through the same set of analyses it has been possible to establish a correlation between the response of the elasto-plastic oscillator and the degrading oscillator, depending on the seismic input duration. Parallel to the study of the global nonlinear response, a numerical study on the out-of-plane response of walls was carried out, developing a simplified assessment procedure based on the use of variable damping displacement spectra and the definition of a suitable effective stiffness and period. This procedure has been validated for simple collapse mechanisms and the extension to more complex mechanisms is currently studied. Detailed nonlinear push-over analyses have been carried out for a representative

building at "rione Libertà" (fig. 6.2). The pushover analyses were also used for a preliminary estimation of the seismic response using code response spectra.
The applicability of the survey form established for monument buildings was tested thanks to its utilization for field survey of historical/monumental buildings at the Benevento old town centre; this allowed to test, at least in a partial way, the validity of the proposed methodology. Moreover, the preliminary analysis of the collected data in a GIS environment provided useful indications regarding the typological distribution of manufacts, the frequent construction characteristics, the main vulnerability causes and the general state of maintenance of the built environment.
Although at the present stage it has been performed only in the linear field, the detailed FEM analysis of S. Sofia church provided several preliminary informations about its seismic behaviour: individuation of vibration modes, definition of construction vulnerable parts, interaction among its elements.

Description of the activities

The elaboration of data collected during the field survey at Rione Libertà and the parametric analyses performed with a preliminary version (that have to be adjusted for non GRLD frames) of the analytical model implemented for simplified analyses of classes of buildings, allowed the recalibration of the survey form initially adopted for r.c. buildings, and its reorganisation on the base of a multilevel approach; such form could be useful in the formulation of guidelines for field survey of r.c. buildings.
In order to find the set of most representative parameters for structural damage on masonry buildings, regression analyses have been performed on the base of results provided by nonlinear parametric analyses (input of more than 400 accelerograms on degrading oscillators with hysteretic behaviour typical of a global response dominated by shear failure). In order to allow detailed push-over analyses it was necessary to implement a suitable pre-and post-processor for the macro-element program SAM (developed at Univ. of Pavia). Moreover, experimental data reported in literature for different types of unreinforced masonry have been collected and statistically processed to obtain threshold values of angular deformation (drift) corresponding to meaningful limit states such as: first diagonal cracking, repairable damage, incipient collapse. These values are used as input data in the assessment procedure just adopted.
In the framework of activities for vulnerability assessment of historical/monumental buildings in the Benevento old town centre, a complete list of monumental construction has been compiled (119 manufacts), providing the geographic assignment of monuments and the field survey based on the proposed survey form, introducing the collected data as GIS ones. As regards the detailed modelling of S. Sofia church, first it has been necessary to collect the graphic-photographic and bibliographic material; this allowed the understanding of geometry and main construction aspects of the church, as well as its anamnesi, transformations and historical seismic damage. A solid 3D CAD model has been implemented, which offered the base for a FEM detailed modelling. Through this model some preliminary analyses (linear, modal and seismic analyses) for the seismic behaviour assessment have been performed.

Task 7: Damage scenarios and methods for the reduction of vulnerability

In charge: G. Magenes

Foreseen objectives in three years time

- O7/1 Definition of the effect, through implemented vulnerability models, of some intervention techniques for risk mitigation
- O7/2 Vulnerability reduction systems based on subsoil treatment
- O7/3 Evaluation of damage scenarios for r.c. buildings
- O7/4 Evaluation of damage scenarios for churches
- O7/5 Evaluation of damage scenarios for Benevento old town centre
- O7/6 Damage scenario modification due to seismic upgrading systems
- O7/7 Guidelines for the employment of advanced composites in the vulnerability reduction of existing structures
- O7/8 Guidelines for soil treatment for subsoil vulnerability reduction

Achieved objectives

The development of mechanical based procedures for vulnerability assessment of r.c. and masonry buildings allows the rational and 'quantitative' evaluation of the effects of strengthening intervention techniques for risk mitigation. Such procedures are in a calibration phase and will be the base for a damage scenario prefiguration. On the other hand, damage scenario for churches will be based on a procedure that follows a hybrid typological/semeiotic approach. The execution of experimental tests on r.c. elements strengthened with CFRP will allow evaluating the effects of such techniques for risk mitigation.

Description of the activities

Activities regarding the vulnerability reduction systems based on soil treatment are at the stage of bibliographic studies, while the analysis strategy has been outlined and is going to start soon. Research moves following two main directions: on one hand, technique assumes to build highly stiff soil layers in order to partially reflect seismic waves, causing the attenuation of the waves that actually reach the surface; on the other hand, second one aims to the realisation of soil layers with a relatively high damping factor, so that the soil itself could be able to partially absorb the energy transferred by the earthquake.

Conclusions

During the first two years the activities of the project fulfilled some of the objectives established for the entire project. In particular, the seismic input expected for Benevento town, based on extended potentially active source models, has been established. Three scenario events of different magnitude have been assumed and for one of them an accelerometric radiation was generated, obtaining fair results in comparison with existing attenuation laws and code spectral shapes.

Site effects have been investigated, and thanks to the mono and bidimensional analyses performed (on the base of the detailed knowledge of geotechnical characteristics of the subsoil) a preliminary microzonation of Benevento town has been proposed. The built environment for r.c., masonry and monumental construction has been classified, the field survey based on specifically developed survey forms for

the three categories is at a final stage and the studies for definition of vulnerability maps based on semi-quantitative and typological methods are in progress. The effect of some strengthening techniques for structures has been evaluated and a GIS platform integrated with the collected databases is under construction.
During the second year of the project, in order to improve the innovative and multidisciplinary connotation of the project, interdisciplinary subgroups meeting with high frequency have been formed:
G^2S (geophysicists, geotechnicists, structural engineers) for the evaluation and improvement of reliability, from an engineering point of view, of the simulated accelerograms;
G^3 (geologists, geophysicists, geotechnicists) in order to investigate, from the geological, geotechnical and geophysical point of view, some soil verticals selected for their significance by the three groups;
G^2 (geotecnicists, geophysicists) in order to numerically and experimentally study the site effects, comparing methodologies from different disciplines;
S^3 (structural engineers for r.c., masonry and monuments buildings) in order to study the homogeneous semi-quantitative and detailed methodologies; structural engineers have already interacted on Liguria project, following the suggestions of the referees.
A state-of-the-art of the project has been proposed at the end of 2002 to Benevento and Campania District local authorities (District Councillor for Research, Major of Benevento, Superintendence for Architectural and Archaelogical Arts, local Professional Boards), (see attach XX). The impact on community has been extremely positive.

Figures

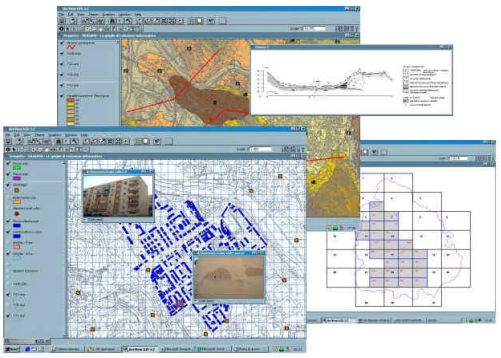

Figure 1.1. GIS structure and data layers.

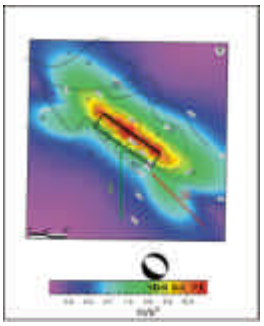

Figure 2.1. 1688 scenario.

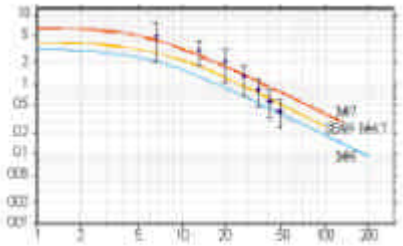

Figure 2.2. SE profile: estimated PGA attenuation and empirical laws.

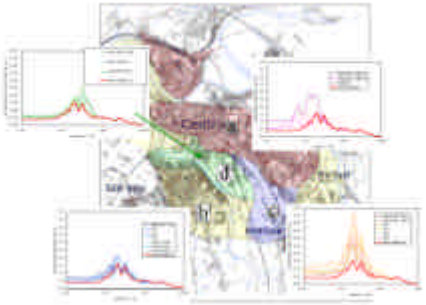

Figure 4.1. Proposed microzonation for the town.

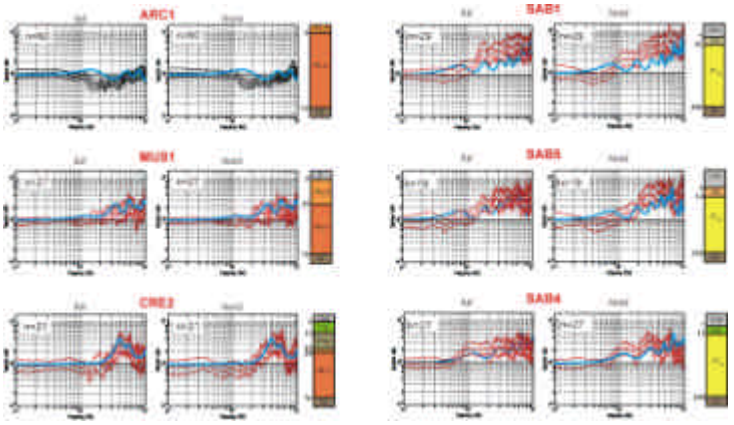

Figure 5.1. 1D theoretical transfer function and relative uncertainties for the different recording stations.

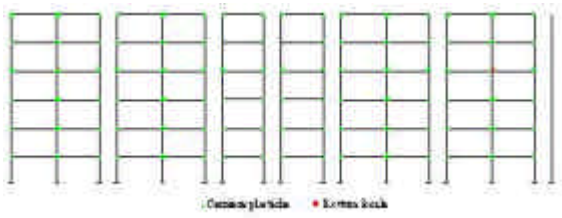

Figure 6.1 a). Transverse frame model and plastic and ultimate hinges.

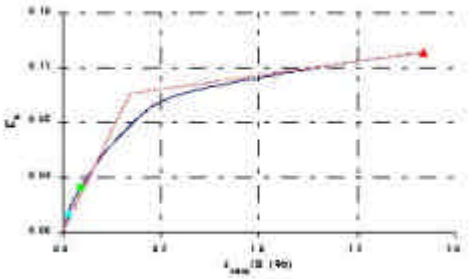

Figure 6.1 b). Push-over curve and bilinear for MDOF-SDOF equivalence.

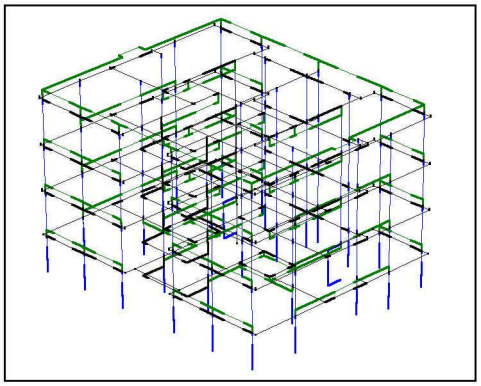

Figure 6.2 a). Tridimensional model with macro elements.

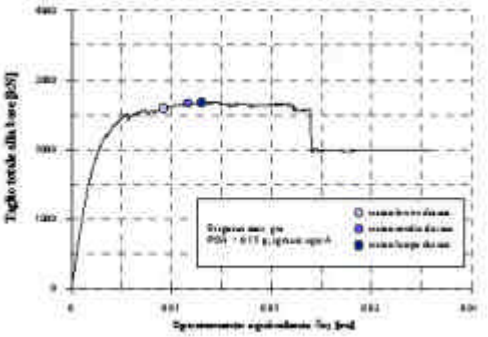

Figure 6.2 b). Push-over curve and estimate of maximum response.

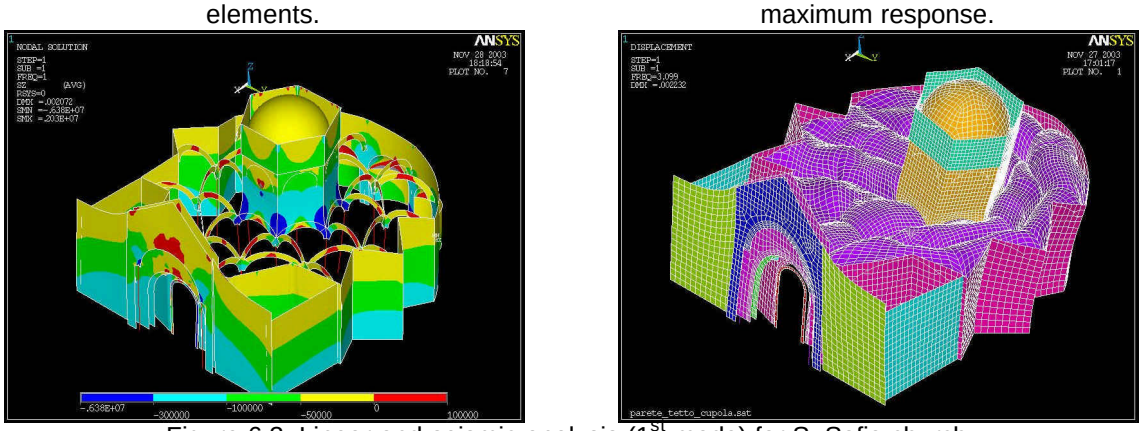

Figure 6.3. Linear and seismic analysis (1st mode) for S. Sofia church.