Reduction of the Seismic Vulnerability of Infrastructural Systems and Physical Environment

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Report on the activities of the second year

The project aims to study the problems related to the vulnerability and to the seismic risk assessment of physical environment and infrastructures and further to apply the implemented techniques and methods to a case study area, located in the vicinity of the city of Benevento, in the following referred to as "test area". The activities of the research group are structured in the 7 tasks: hazard definition, physical environment, road networks (bridge and retaining structures), electrical networks, main industrial plants, earth dams and GIS development.

The global objectives of the project can be summarized as in the following:

- categorization of vulnerable structures and systems in the test area;
- development of simplified models for vulnerability assessment of infrastructural systems and physical environment (both deterministic and probabilistic approaches are considered);
- implementation of a Geographic Information System (GIS) for management, correlation and visualisation of the fundamental parameters of seismic risk, vulnerability and hazard analyses;
- implementation of multilevel procedures to be integrated with the GIS and to be used for automatic and interactive risk evaluations of infrastructural systems and physical environment (both off-line and on-line procedure);
- development of innovative methods for the vulnerability reduction concerning: soil treatment, use of isolating and dissipating devices, use of advanced composite materials as fibre reinforced polymers;
- preparation of maps and data for the emergency planning: expected damages, alternative routes, environmental effects.

The main activity of the first year consisted of a data gathering for the definition of the test area seismicity, census and survey of infrastructural systems, acquisition of the cartographic instruments for the GIS implementation, theoretical study of numerical models for hazard, vulnerability and risk evaluation.

The second year activities have been focused on more practical aspects of the research programme. Firstly a prototype of GIS has been implemented by the Research Unit of Pavia-DIET (Task 3 "GIS development"). The GIS, consultable at the web site http://geo-survey.unipv.it/progvia, contains the first results of the hazard and risk analyses of the test area; it includes specific software for the database test and for the correlation with territorial data. The Research Units of the Task 1 ("Seismic input") have defined the seismic hazard in the test area, as well as theoretical models for refined evaluations. The research of the Task 2 ("Vulnerability of physical environment") has been focused on the zonation, the development of a database system of the potentially unstable landslides under seismic events, the geological survey of the test area in order to determine the high risk sites. Task 4 ("Vulnerability of road networks") activities has been focused on specific topics

concerning vulnerability evaluations, risk evaluations, correlations between local and global limit states of the bridges and of the entire road network. Guide-lines for vulnerability evaluations of bridges have been also prepared. About the Task 5 ("Vulnerability of electrical networks"), the Research Units involved have carried out a fundamental study on the mechanical properties of the components of an electrical high-voltage station and of methods for the vulnerability reduction. For this purpose a relevant experimental activity has been performed for the mechanical characterization of the isolator devices and for the development of the corresponding analytical models. In the Task 6 ("Industrial plants") guide-lines for vulnerability evaluations of existing and under-designed pre-cast structures with long span elements have been produced. In the Task 7 ("Earth dams"), the mechanical characterization of the materials and of the foundation soils has been carried out, as well as a numerical modeling of the boundary conditions. The most interesting aspects of the GIS in its latest development are: a) the implementation of the procedures for the seismic hazard assessment of a generic site in the test area and for the risk evaluation following a deterministic approach; b) the updating of cartographic data.
The results presented in the following appear to be in satisfactorily agreement with the global objectives of the project and with the assignments of each Task.

TASK 1 – "SEISMIC INPUT AND SITE EFFECTS"

By: Dr. A. Herrero, ING - UniNA-DSF (Coordinator)
UniCAL-DDS *Prof. F. Silvestri*
UniNA-DIG *Prof. F. Vinale*

The objective of this Research Unit is to define the seismicity of the test area as a function of the location of the examined structures and to develop new methods to improve the seismic hazard assessment. During the second year some opportune methods have been implemented and consulting on seismic input and specific computation has been provided to the other Research Units. The theoretical research on the probabilistic analysis of the seismic hazard has been further developed.
The research on the seismic input focalised on the probabilistic approach of the hazard (Cornell, 1968), based on the definition of source zones characterised by an homogeneous seismicity in respect to the Gutenberg-Richter law. If an attenuation law is introduced, which for given magnitude–distance couples gives the acceleration peak, it is possible to estimate the exceeding probability curve for a given site. From the given curve, fixing the exceeding probability (e.g. 10%) on a given time window (generally 50 years), the threshold acceleration may be estimated. The computation of such a curve may be realised also for a set of sites covering a given area (seismic hazard map). The exceeding probability curve of a given site represents the basic seismic input requested by the other Tasks of the Project. In order to realise the computation of the seismic input with the probabilistic approach, the closest to the test area sismogenetic zones has been considered (fig. 1). The values of the seismicity rate λ, the *b* value of the Gutenberg-Richter law and the maximum value for the magnitude in each zone are compiled in the table 1. The acceleration peak often is not sufficient for a detailed study of the response of structures subjected to the seismic excitation. Empirical relations (Sabetta & Pugliese, 1996; Ambraseys et al., 1996), based on the philosophy of attenuation laws for the computation of the

peak ground acceleration exist in the literature. Those relations can express the variation of a given spectral ordinate (e.g. PSV) for a given natural frequency as a function of the distance, of the magnitude and of the damping. Using these relations in the probabilistic approach, it is possible to estimate the probability to exceed the spectral parameter depending on the natural frequency for a given site and a given time window. This result is represented in a three dimensional graph in the figure 2.

The aim of this Task also consists in the development of new methodologies. One of the fundamental aspects of the research is the introduction of a priori information in the seismic source of the probabilistic seismic hazard analysis. This information, introduced at the level of the attenuation law, consists of the radiation pattern associated to the focal mechanism, the directivity effect, the fault finiteness effect or the focal depth. During this last year, our research has been concentrated on the influence of the focal mechanism on the result of the probabilistic analysis of the seismic hazard; the research developed has allowed the introduction in the probabilistic approach of a priori information on the focal mechanism. This means that a given seismogenetic zone will not be only defined by the seismicity rate, the *b* value of the Gutenberg-Richter law and a maximum magnitude but also by a focal mechanism or better a distribution of focal mechanisms (e.g. 20% of strike slip faults and 80% of normal faults).

For a given site the result is expressed in terms of a single value of ground acceleration, it can be complicated to define the magnitude – distance couple to be really associated or having the more contributed to this result. This type of study is called *deaggregation* and its use is more and more employed in probabilistic seismic hazard studies. This study allows defining the design earthquake on the basis of a probabilistic approach, starting from the annual exceeding probability. Because we have introduced a priori information in terms of radiation pattern in the probabilistic seismic hazard analysis, with a mathematical expression relying on integration techniques, it is possible to apply the deaggregation technique also to this type of parameter. The figure 3 shows the marginal probability density function for all the parameters. The new and interesting result is observed in the case of the focal mechanism: it demonstrates the very high influence level of the fault dip on the seismic hazard. The objectives of the second year activity have been satisfactorily reached and they are in accordance with the initial assignments.

TASK 2 – "VULNERABILITY OF PHYSICAL ENVIRONMENT"

By: Prof. F. Silvestri, UniCAL-DDS (Coordinator)
UniNA-DIG *Prof. F. Vinale*
ANAS *Dr. A. Capuani*

The main outcomes of this Task in the second year of the project are: a) the zonation of the instability risk of physical environment at Grade II through pseudo-static analyses; b) the development of a database model of the potentially unstable landslides under seismic events and the application to some active landslides in the zone of interest; c) the geological survey of the test area to study with Grade III methods; d) the determination of the high risk locations, to study through dynamic methods. Such outcomes result slightly modified with respect to the initial assignments because of the necessity, felt during the second year, to proceed with increasing detail of knowledge of the subsoil properties.

Among the seismically induced phenomena of large ground deformation, the analyses of liquefaction and subsidence risk have a marginal importance level in respect of natural slope stability analyses. Therefore, it was decided to proceed to the analysis and zonation of the risk of landslide in a more restricted area, where several landslides directly interacting with the road (fig. 4), formerly catalogued in the official mapping by the National Basin Authority, have been already implemented in the 'Map server'. The method of analysis and zonation adopted required, as essential information, the collection and the synthesis of available data, to individuate areas comparable in terms of lithological and physical-mechanical properties. The geotechnical characterisation of the different geomaterials was possible through the processing of data resulting form field and laboratory investigations executed in the test area; each vertical profile has been geo-referenced, located in the 1:25.000 map and connected to the server GIS in terms of synthetic summary table.
A datasheet prototype for landslides falling in seismic areas was set up, based on examples published in literature (Andrighetto, 1994) or used by the Basin Authorities (Regione Calabria, 2001). The datasheet, prepared in ACCESS format, is divided into three sections: - general data (basic information, available cartography, shape and size of the landslides); - geomorphological data (slope morphology, kinematic classification, state of knowledge); - geotechnical data (borehole identification, layering, experimental data from the samples). The datasheet was used during the 1:10000 scaled geomorphological surveys, which brought to the map of the active landslides in the test zone, in order to describe some of the active landslide. The previous Task calculated the probabilistic hazard curves in accordance with the classical 'Cornell approach' for a reference period of 50 years, the uniform hazard respose spectra related to an exceeding probability of 10%.
As mentioned above, the geological survey at 1:10.000 scale were fulfilled, obtaining a more detailed description of the deposits and a more reliable location of the active landslides. After such survey, two very interesting sites were individuated for the successive studies of Grade III: a) a flow in a Pliocene clay deposit; b) a complex mechanism of multiple sliding involving different geomaterials. For such landslides, the longitudinal sections at 1:10.000 scale were produced, and it is expected to submit them to more accurate studies in the 3° year of the project. After to have setted up the methodology in the first year, the second year activity was mainly dedicated to the studies on the test area; a satisfying level of knowledge was attained about the geological and geotechnical characteristics of the deposits. The topographic, geological and geomorphological mapping, edited at 1:25.000 and 1:10.000 scales, is already available to be connected in the GIS, and ready to the production of micro-zonation maps with both Grade II (in terms of safety factors) and Grade III (in terms of displacements) methods. The geotechnical characterisation of the deposits results practically completed and of satisfying reliability, even if is certainly hampered by the difficult retrieval of existing geotechnical data and by the often low reliability of them.
The definition of the reference hazard is quite completed: soon deterministic scenarios will be processed to produce microzonation maps, with reference to both a recent (Irpinia 1980, MS=6.9) and a historical strong-motion event (Sannio 1688, I=X). Amplification coefficients according the recent suggestions of EC8 will be applied to the predicted distributions of peak accelerations on stiff outcropping. For

the active landslides vulnerability and risk analyses will be on the other hand developed according to probabilistic approaches, with references to the curves produced by the previous Task.
The objectives of the second year of the Project have been achieved.

TASK 3 – "GIS DEVELOPMENT"

By: Prof. R. Galetto, UniPV-DIET (Coordinator)
All the Research Units

Accordingly with the initial assignments, the activities of the first year were: a) definition of GIS conceptual model; b) definition of the test area; c) acquisition of the territorial geographic and thematic data; d) identification of the more appropriate hardware and software to set up the GIS prototype; e) implementation of the first prototype.
Notable amount of descriptive data have been acquired (basic national cartography, thematic maps, digital ortophotos) during the first year. In order to allow the on-line consultation of GIS data by the Research Units and to completely use the new capacities, the realization of a Map Server was decided, instead of a stand alone GIS.
The activities of this Task during the second year were focused on: a) the upgrading of the GIS with new cartographic territorial data and descriptive data of the infrastructures; c) the web server realization; d) creation of a Map server in ESRI environment and implementation of utilities for the management of infrastructural data; e) development of functionality for the simulation of earthquake effects according to the deterministic approach; f) creation of the Map server with Java based software; g) optimisation of raster images and data transmission management.
Working in ArcInfo environment, IGMI 1:25.000 and 1:100.000 scaled cartography of the test area was provided. The GIS was provided of several thematic maps (e.g. map of urban installations of the infrastructures and map of the vulnerability of the urban and infrastructural pattern). A utility expressly related to the on-line visualization of the cartographic data and of an opportune legend has been created.
The following data, transmitted from the other Research Unit to the Unit of Pavia-DIET, were inserted into the GIS as vector entities: a) 40 bridges of various typologies; b) 26 electric power stations; c) an industrial plant.
A database was created in order to store detailed information of bridges (structural details, photos, PGA values associated to the yielding of the structural elements or collapse events). The seismic hazard representation of a particular location is numerical modelled by the calculation of the PGA as a function of the magnitude, of the epicentre coordinates and of an attenuation law. The state of the structures after the seismic event is displayed in terms of tabular report (fig. 10). In this table the PGA values deriving from a vulnerability analysis and the PGA associated to the seismic hazard of the location are compared.
A comparative evaluation (advantages/shortcomings) of the properties of different environments that can be used to implement a Map server was studied; a new solution was realized, using open-source components and interface in Java language with the same characteristics of the previous Map server. Particular care was dedicated to the management of raster images; the initial response time was drastically reduced by one order of magnitude using opportune software.

The research work developed during the second year of activity perfectly agrees with the initial programme, the objectives planned have been reached. Furthermore, the realization of the GIS on the net through the creation of a Map server is an important improvement, if compared with the initial assignments.

TASK 4 – "VULNERABILITY OF ROAD NETWORKS"

By: Prof. P.E. Pinto, UniROMA1-DISeG (Coordinator)
UniPV-DMS *Prof. G.M. Calvi*
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ANAS *Dr. S. LaMonica*

The second year activities of the Research Units of this Task consisted in the development of the research work of the first year. The objectives set in the general programme were: a) realization of guidelines for the evaluation of seismic vulnerability of bridges; b) implementation of numerical procedures for the evaluation of the seismic vulnerability and risk, to be implemented in a GIS developed specifically for this project; c) calibration of the graph of the road network; d) definition of the traffic loads on the road network of the test area.
The first three results have been actually achieved; on the contrary, the lack of available data has forced to postpone the completion of the fourth objective. On the other hand, the argument "vulnerability of road networks" (planned in the third year) has been developed ahead of time. State-of-the-art methods have been employed and, in some cases, original procedures have been specifically set-up.
The Rome Unit has progressed in the area of probabilistic approaches, developing a procedure for the assessment of seismic risk of road networks. The starting point is the evaluation of the fragilities of the bridges located in the network. The survey made on the test area has shown that simply-supported bridges represent by far the majority of all bridges. For the purpose of the analysis, their piers can thus be modelled as a single-degree-of-freedom (SDOF) oscillator. The statistics of the maximum dynamic response of such model have been derived through simulation. With the capacity of the generic pier being known, and assuming that both capacity and demand are log-normally distributed, the probability of failure has been estimated by my means of a FORM analysis and represented in terms of fragility curves. In order to calculate the fragility curves (fig. 5), the mean values of the maximum displacement ductility demand have been calculated as a function of the natural period and of the design factor; 41 natural records, with a bi-linear, Takeda type, constitutive law, and 5% damping were used. The road network is composed of several sections, which connect each other at the nodes of the network. Several bridges can be located along each section. The functioning of the system is assumed as of pure connectivity, and in addition the behaviour of the elements is considered as binary: transitability or traffic interruption. Failure of the network to function after a seismic event is defined as the lack of connectivity between any two points of the net. Failure probability of the section is evaluated assuming a serial system, whose components are the bridges. To estimate the failure probability of the network, minimal cut-sets theory and the Ditlevsen bounds are employed.
The Unit of Pavia has progressed the deterministic-oriented study: the computer code SVVS for the seismic vulnerability evaluation of RC bridges has been further developed and applied to most of the bridges in the test area whose data were

available. Different global limit states are considered in the procedure: full practicability, reduced flow limited to emergency vehicles, bridge collapse. Each limit state is defined on the basis of the local state of damage, quantified by mechanical parameter values (residual displacement, curvature ductility, shear and flexural strength). The type of numerical procedure used for the evaluation of the seismic response of a bridge (DDBA, direct displacement based assessment) depends on the structural typology. The behaviour of the bridge under increasing lateral load is express by mean of a push over curve and the results are expressed in terms of force – displacement and moment – curvature curves. The global response of the structure is then compared with the behaviour of the SDOF system, characterized by a period of vibration, a ductility level, an equivalent damping (Kovalsky). Chosen an elastic displacement spectrum (EC8) for a given soil type and appropriately reducing it to account for the required damping, the spectral displacement for a PGA equal to one at the equivalent period is readily available. The PGA associated to the considered limit state can be simply evaluated as the ratio between the limit-state displacement and the previously calculated spectral displacement. The procedure outlined above has been applied to most of the bridge in the test area whose data where available. In the figure 6 the results relative to the highway viaduct "Sambuchi" are shown, as an example. The two methodologies briefly described in this report, the probabilistic one and the deterministic one, have been implemented in the GIS database by the Unit of Pavia - DIET in charge of its development. Given magnitude and coordinates of a seismic event as input data to the GIS, it returns both the state of the entire network and of each single bridge after the earthquake.
As opinion of the Units of this Task, the objectives of the second year activity have been satisfactorily reached.

TASK 5 – "VULNERABILITY OF ELECTRICAL NETWORKS"

By: Prof. R. Giannini, UniROMA3-DiPSA (Coordinator)
UniROMA1-DISeG *Prof. P.E. Pinto*

The aim of the second-year activity was the analysis of the mechanical behaviour of components of an electrical high-voltage station, of their vulnerability and systems for reducing it. At this purpose a relevant experimental activity, beyond that theoretical study, have been performed for the mechanical characterization of the isolator devices and for developing the corresponding analytical models. For characterizing the mechanical behaviour of electrical equipments and the ceramic material that are made of, is on the way a wide experimental activity. The light delay in concluding the previous point is compensated by the advance on one of the third-year target: setting up an computerised procedure, already available, for the evaluation of the seismic hazard of the national electrical network.
In the Laboratory of the University of Roma Tre experimental tests for characterizing the cyclic behaviour of steel cable dampers (Wire-Rope) have been carried out. Wire-Rope isolators consist of a unique twisted stainless steel cable. The mechanical flexibility of the whole cable gives to the device optimal isolation properties in all three directions, whereas the sliding friction between the intertwined cables gives a high dissipative capability. On the base of three different wire-rope typologies, imposed displacement cycles, with frequencies variable in the range 0.1-3 Hz, have been carried out. In figure 7 some examples of the cyclical behaviour of isolators are

shown. A common characteristic of all cycles is the stability and independency of the excitation frequency, whilst the cycle shape strongly depends on the stress direction. In the Tension/Compression case the cycles are asymmetric with softening in compression and hardening in tension. The relative damping ratio is about 15-20%. The cyclic behaviour for shear stress is symmetric with equivalent stiffness strongly dependent on the normal stress. If the compressive stress increases, the stiffness decreases. The dissipation capability is higher for shear in longitudinal direction. The last part of the experimental activity of the second year is already in advanced phase of execution and regards static tests on electrical equipments of the electrical sub-station of Valmontone (electrical insulators and TA current transformers). The purpose of the test is to carry out the ultimate resistance of any element. This information is a necessary step for the next phase (fragility analyses of the electrical component). In order to numerically simulate the seismic behaviour of base-isolated electrical equipments, the cyclic behaviour of wire-ropes has been modelled, for shear and roll, using the classical Bouc-Wen model. For the tension/compression case has been necessary to adopt a partial modification of the model. The parameters used (in terms of typology and actions) give a response satisfactorily closed to the experimental data. Subsequently, numerical analyses, for the evaluation of the seismic response of high-voltage electrical equipment, have been carried out. Using a 5 d.o.f. model, the seismic response of a 420 kV electrical breaker base-isolated with four wire-ropes have been simulated. The time-history of base-shear with and without isolation system clearly shows its effectiveness.
About computational tools for seismic reliability analysis of electric network, the state-of-art is represented by ASKxELP [Giannini and Vanzi, 1999], a program based on Monte Carlo procedures. Aiming to include the effects of spatial variability of ground motion, that can produce damage localization and thus disconnection of network architecture, the PGA value in space, F(x,g,qm,qv), has been treated as the sum of a deterministic component, as given by attenuation law commonly used in earthquake engineering and a zero-mean random term, e(x,qv), where x denotes position, g represent the other observable quantities affecting the random field, while qm and qv are the parameters required to model respectively the mean and the random component of the field. A statistics measure of the random fluctuating component is represented by the auto-covariance function: $C_{FF}(\mathbf{x}_1,\mathbf{x}_2,?_v) = Cov\left[e(\mathbf{x}_1,?_v)e(\mathbf{x}_2,?_v)\right]$, where $\mathbf{x}_1$ and $\mathbf{x}_2$ are two spatial locations. Different methods able to assess the correlation structure from experimental field data are available in literature and object of study in the next year activity of the research program. Wishing to integrate the ASKxELP Monte Carlo procedure generating a statistics of $F(\mathbf{x},\mathbf{g},q_m,q_v)$ close enough to the target, the sample correlation has been obtained through a Cholesky decomposition of correlation matrix and for non-Gaussian fields, completing the procedure with the techniques described in [Liu and Der Kiureghian 1986].
The methods are in accordance with the initial assignments and the objectives of the second year have been reached.

TASK 6 – "VULNERABILITY OF INDUSTRIAL PLANTS"

By: Prof. G. Manfredi, UniNA-DAPS (Coordinator)
UniPV-DMS *Prof. G.M. Calvi*
UniROMA1-DISeG *Prof. P.E. Pinto*
UniROMA3-DiPSA *Prof. R. Giannini*

This Task develops a dual study on the vulnerability evaluation of pre-cast structures and of industrial plants, in particular the petrochemical facilities. The objectives of the second year are: a) the realization of guide-lines for the evaluation of the vulnerability of existing and under designed long span pre-cast structures; b) the assessment of parameters for vulnerability and risk evaluation of petrochemical facilities.
In order to outline the first objective, the structural characteristics of pre-cast industrial buildings made in Italy in the '60 and in the '70 are analysed on the base of the study of actually constructed structures. A case study is presented: a precast industrial building, properly identified as representative of a class of structures built in the reference period, is analysed in the non linear field of behaviour, under vertical and horizontal loads; many cases are studied, since different models of the elements, of the connections and of the roof have been considered. The influence of some parameters, as the deformability of the beam to column connections and the phenomenon of the "fixed and rotation" on the building capacity have been evaluated by push over analyses. The collapse of the reference building is due to the plastic hinge at the column bases, which also anticipates the beam-column connection failure. Only in the case of smooth re-bars without hook at the column-foundation connection, the collapse is due to the pull-out mechanism and, consequently, the structure exhibits a very bw ductility. Results of simplified spectral analyses basically confirm the conventional calculation, even if the role of "fixed-end rotation" at the base column seems to be important. About the second objective, condition of the Italian territory in term of industrial risk was analysed. Industrial installations matching the European risk guidelines definitions (Dgls 334/99 "Seveso Bis" art. 6 and 8) have been considered. Data coming from the Environmental Ministry census (2001) cataloguing the "risk" facilities were crossed with the seismic classification map of Italy provided by Italian Seismic Survey. It was possible to roughly quantify the seismic risk in terms of number of plants per region not only in the project's test area but on the whole national territory. Seismic vulnerability has been focused on welded steel tanks for oil storage. Contemporary simulation based and reliability analysis for tanks have been designed by a response surface approach. Limit states considered in the reliability analysis are: shell buckling and sliding of unanchored thank. Partial results were implemented in the G.I.S. System in cooperation with the Research Unit of Pavia-DIET. Currently a 3D model is under development and on line consultable. Detailed design criteria and guidelines reference are also implemented for the same plant as well as a vulnerability sheet, associated to each steel tank.
The research developed in the second year perfectly agrees with the planned assignments.

TASK 7 – "VULNERABILITY OF EARTH DAMS"

By: Prof. F. Vinale, UniNA-DIG (Coordinator)
UniCAL-DDS Prof. F. Silvestri

During the first year of activity, attention was focused on a wide literature search aimed at outlining possible types of damage that strong-motion earthquakes could induce to earth dams as well as theoretical and numerical approaches available in literature for analyzing their seismic behavior. A well-documented case-history (the "Camastra dam", near Potenza) was selected as a sample dam to which procedures suitable for seismic safety assessment could be applied. The second year's research activity was focused on the mechanical characterization of construction materials and foundation soils and numerical modeling of the boundary value problem.

Reliable predictions with respect to dam safety against global instability and freeboard loss require a plausible seismic scenario in terms of acceleration time histories and a theoretical framework able to model the effects of such input motions on the dam. A reliable theoretical framework should be able to account for all features affecting soil response: stress history dependency, hysteresis, liquefaction, cyclic mobility and ratcheting. After the wide-ranging research activity of the first year, a sample dam was identified and a fully coupled dynamic approach was adopted as a predictive tool of its seismic behavior. Inside this approach the soil skeleton stress-strain behavior of the core and shell materials is modeled by the elasto-plastic multi-mechanism constitutive law developed by Aubry et al. (1982) and by Hujeux (1985). This model reliably reproduces the main features of the soil's non-linear behavior over a wide range of strains. The set of governing equations, solved with the finite element technique, is implemented in the Gefdyn code. The planned research work consists of determining monotonic stress-strain response for all strain levels firstly from available laboratory and in situ tests and then from a back-analysis of monitoring data. The cyclic behavior will be instead defined parametrically based on literature data.

Significant effort was given to in situ experimental activities in this second year. The SASW technique was applied in order to determine soil stiffness at small strain levels for both core and shell materials. One alignment (2 receivers and 2 vibration sources) was set up along the dam crest to investigate core stiffness properties. Two alignments were used along two downstream shell blankets of the dam and one was used at the base foundation to determine the shear wave velocity of both the shell material and the foundation soils. In addition, an accelerometer monitoring system was, designed and installed. The possible roles that such a system could accomplish during the dam life are summarized in the following points:

a) The overall mechanical response of an earth dam during earthquakes will be affected by previous loading history; accelerographs installed at the dam base foundation complete the knowledge about loads a dam can be subjected to during its history. Likewise, as construction history provides the dead load during construction and impounding history provides static and hydraulic condition at wet boundaries during operation, accelerometric time histories at the dam base-foundation provide the dynamic loads that shake the dam during an earthquake.

b) Accelerographs installed at the base foundation and at other points along the dam body allowed information about seismic waves filtered through the dam body.

The static stages (construction and first impounding) of the Camastra dam were

numerically simulated to check and recalibrate the soil constitutive parameters. By a back-analysis procedure of the static stages of the dam life, a set of parameters fitting settlement and pore pressure during construction and first impounding were identified. Bi-dimensional analyses were carried out using the simplified hypothesis of plane strain and assuming stiffness dependency on mean effective stresses.
The second year's research activity had as its main focus in: a) the mechanical characterization of construction materials and foundation soils, b) the numerical modeling of the boundary value problem by using different methods of analysis.
In the opinion of the research group UniNa-DIG, each of the above outlined objectives were accomplished satisfactorily.

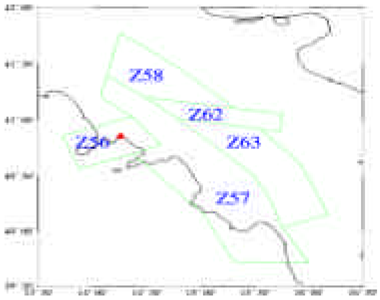

Fig.1. Map of the 5 source zones of the test area.

Zona	l (tasso di sismicità)	b (Gutemberg-Richter)	Magnitudo max
Z56	0.004	0.7278	6.2
Z57	0.10	0.9295	5.0
Z58	0.088	0.5850	7.3
Z62	0.091	0.5722	6.7
Z63	0.315	0.6716	7.0

Tab. 1: Summary table of the maximum magnitude of the 5 zones in the test area.

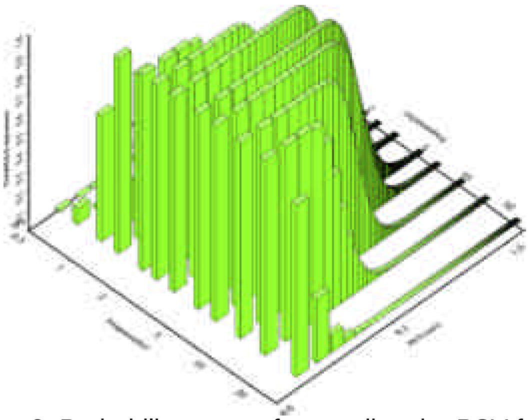

Fig. 2. Probability curve of exceeding the PSV for different natural frequencies.

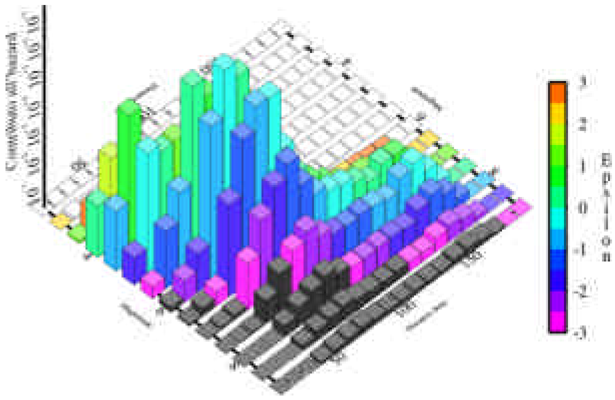

Fig. 3. Contribution to the seismic hazard as a function of the distance and the magnitude.

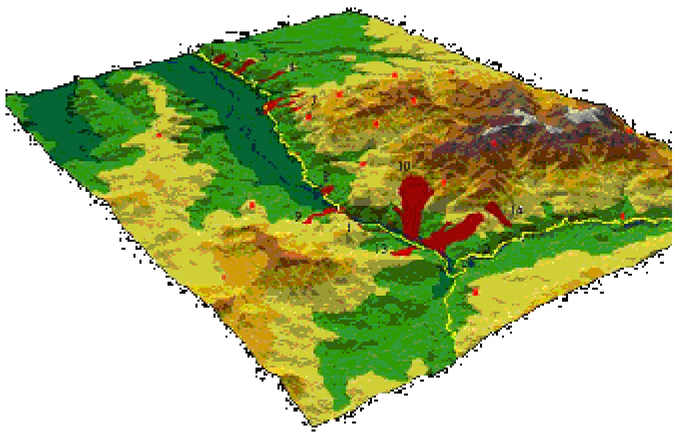

Fig. 4. Digital 1:25.000 model and unstable areas in the reference zone.

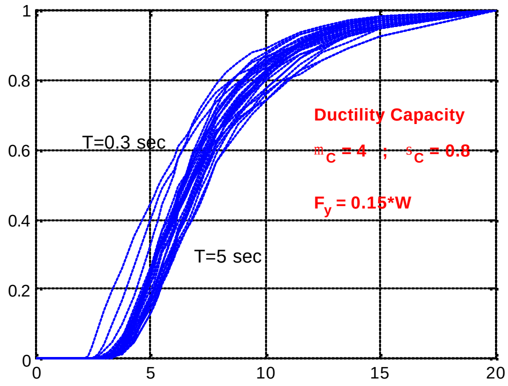

Fig. 5. Fragility curves for given ductility capacity and strength.

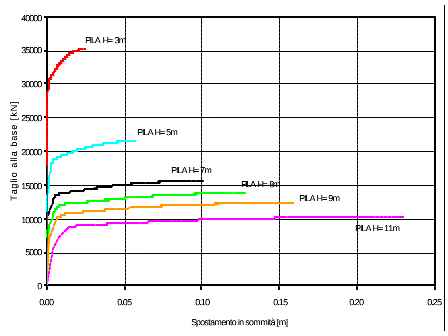

Fig. 6. Sambuchi Viaduct:
force – displacement curves of each pier.

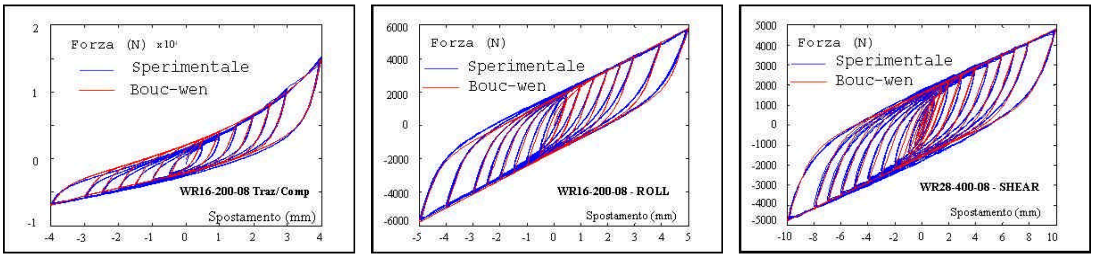

Fig. 7. Examples of experimental cycles and comparison with the proposed model.

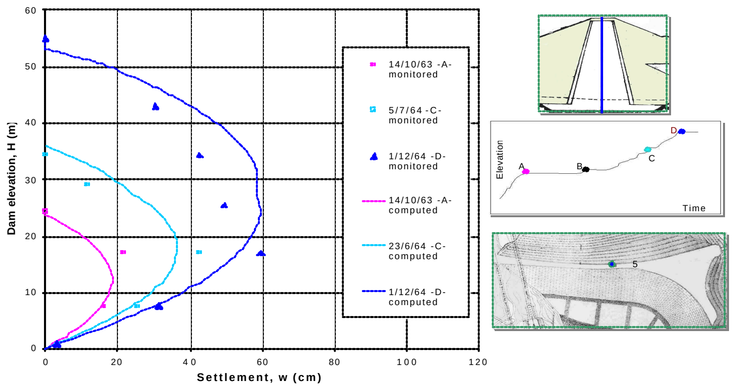

Fig. 8. Prototype dam: comparison between calculated and experimental settlements.

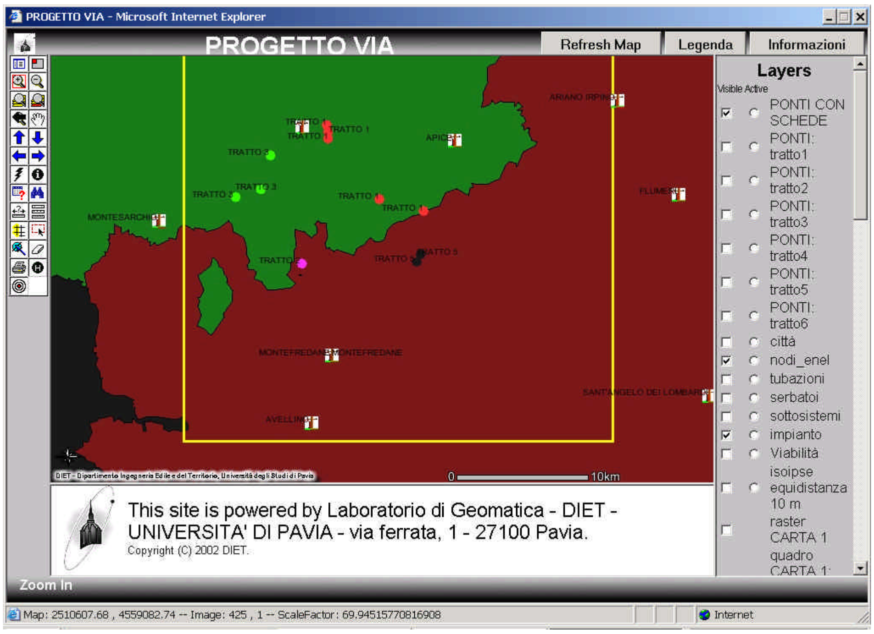

Fig. 9. Example of "Map Server" window.

Caratteristiche Sisma				
Coordinate Ipocentro			Magnitudo	Parametro tipo di terreno
Nord [m]	Est [m]	Profondità [m]		
4551196	2505018	1500	7	1

Risultati della simulazione								
Nome	Tipo	Nord [m]	Est [m]	Dist. Ipocentro [Km]	PGA snerv.	PGA collasso	PGA simulato	Stato
DENTECANE	viadotto	2511350	4542749	10.198	0.24	0.9	0.476	Parzialmente agibile
DEL DUCA	viadotto	2511030	4542126	11	0.11	0.75	0.449	Parzialmente agibile

Fig. 10. Report of the post-seismic state of the examined structures.