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Environmental Geotechnics to Study a Historical Town

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ENVIRONMENTAL GEOTECHNICS TO STUDY A HISTORICAL TOWN

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ABSTRACT

The present paper summarizes the original approach, the different stages and the most innovative results of an interdisciplinary research activity, carried out on the subsoil of a historical site, in a seismic area, in Italy: the old town of Potenza, capital of the Basilicata Region. The entire Research-work has been designed and implemented within a total period of about 3 years. The paper is divided into twelve paragraphs and is organized logically, so that the reader can follow the development sequence of the different, interdisciplinary activities, detailed in the *"Research General Flow-Chart"*. After the *Introduction* [paragraph **1.0.0**], the *Philosophical Approach* [paragraph **2.0.0**] is described and then, an *Overview of the Entire Research-work* [paragraph **3.0.0**] is outlined. Described and discussed, in the paragraphs from **4.0.0** to **10.0.0**, are the basic methods together with the main procedures and results, developed within seven large Thematic Areas: "Historical Research", "Remote Sensing Integrated Analyses", "Geomorphology", "Geolithology", "Investigation Program", "Hydrogeology", "Geotechnics and Foundation Analyses". The paragraph **11.0.0** is devoted to an *Overview of the final Data Processing* and the last paragraph [**12.0.0**] addresses the *Closing Overview*.

1.0.0 INTRODUCTION

1.1.0 Geotechnics in the Decision Process of a Historical Town Restoring: Strategic Goals

When I presented a paper on environmental geotechnics, in 1984, in the "First International Conference on Case Histories in Geotechnical Engineering", I wrote: «*...It is by now a common opinion that the contribution of geotechnics is much more useful in suggesting indications when planning than in finding solutions [often difficult and expensive] to problems which may occur after the decision-making process…*» [Ciuffi, 1984]. Our "Research-Institute" had developed environmental geotechnical procedures, beginning from 1978, performing researches on the prediction of the environmental effects that could occur after the construction of the larger earth dam in Europe. The said procedure was also discussed within the Tenth ICSMFE, in Stockholm [1981].
Thus, it is a pleasure to note that, in the recent years, many advances have been made. It can be observed that the problem of studying the role of geotechnics in land-use planning has attracted the attention of several investigators. A devoted Technical Committee [No. TC 5] has been also created, within the ISSMGE [International Society of Soil Mechanics and Geotechnical Engineering].
In addition, it should be noted that the matter becomes even more attractive if it has to be discussed a case history on the role of *geotechnics in the decision process of a historical town restoring.* Even more important, in fact, is, in this case, the contribution of the Historical Research, together with its fascinating secrets [Kerisel, 1991].

In this context, in the present paper it will be examined, as far as space permits, the complete Research process of a laborious and innovative interdisciplinary Research-work, implemented on the subsoil of a historical town, in a seismic area, in Italy.
The paper is organized logically so that the reader can follow the development sequence of the different, interdisciplinary activities, graphically shown in the *"Research General Flow-Chart"*. All the twelve paragraphs together with the sub-paragraphs are deliberately numbered and bold-typed [only the paragraphs] to facilitate cross-referencing and the comprehension of the synergies and interconnections, among the seven Thematic Areas.

Potenza, the capital of the Basilicata Region, is to the south of Rome [nearly 300 km], in a seismic area [**Fig. 1**]. In the past, this Region was greatly damaged by a number of earthquakes. Also the very strong earthquake of 23rd November 1980 caused great disasters: many structures collapsed killing more than 4.000 people, within the entire area.
The city of Potenza is located on different hills: the historical town is on a hilly ridge [823 m. above s.l.], long and narrow,

oriented on a N.E. – S.W. axis. This part of the city was the most damaged by the 1980 earthquake: the famous old Cathedral [IV[th] century] and other churches, all the monuments and a very large part of the buildings [mostly, ancient masonry structures] suffered very heavy damages. For this reason, the historical town was uninhabited for years.

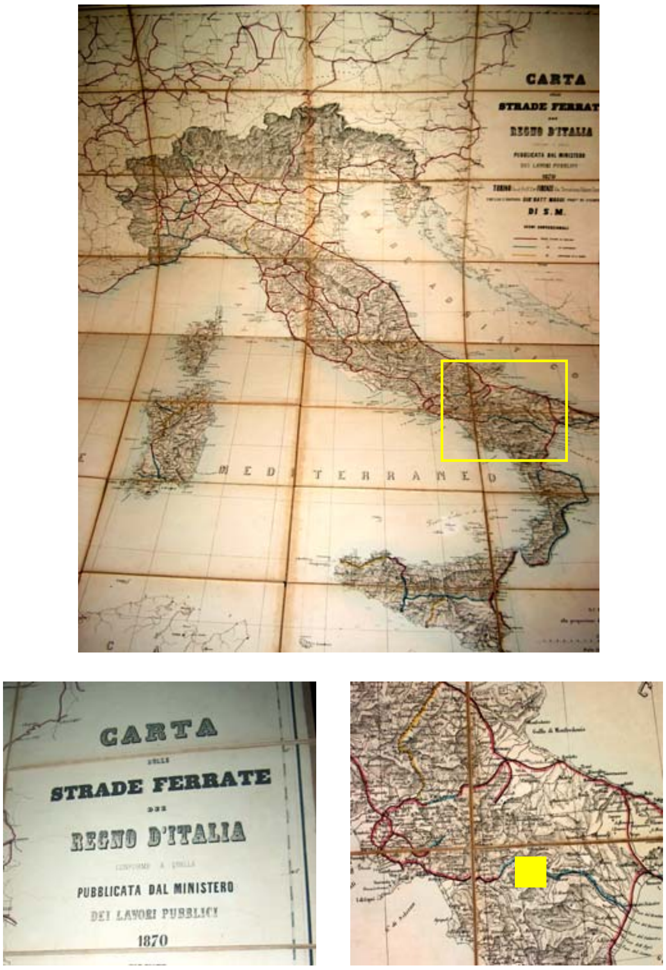


Fig. 1. *A Historical Map (1870) Showing the Location of Potenza*

In order to plan its restoration and new development, the City Council organized two scientific teams, called to participate in the decision process: the first of town planners; the second one, called *geotechnical team*, focused on the subsoil conditions and characteristics. The strategic objective of the *geotechnical team* is summarized as follows: **to know, in detail, the different aspects of the subsoil conditions within the historical town, in order to organize a *geotechnical integrated system*, a quantified tool, useful for town planners and for further engineering and design activities**. For this purposes, two main lines have been fixed:

[i] "Reconstruct the morphological history" of the hill and Analyze the different changes occurred within the subsoil.

[ii] Study the details of the subsoil features, by geomorphological, hydrogeological and geotechnical point of view.

1.2.0 The Research Team

A central feature of this Research-work has been the interdisciplinary approach, as later better discussed.
Different skills and capabilities have been aggregated to develop the Research activities, not just as an "assembly line" which adds on various specific contributions without any mutual integration. The Research-team has been set up with the aim of asking questions to question ourselves and give concrete implementation to the ability to study and analyse together, so as to create new knowledge together.
Many eminent scholars and investigators of the Research-team operate, today, within the **«*intra*Vidére»** Research-Institute.
For this reason, it may be appropriate to speak a few words about the said Research-Institute.

The company **«*intra*Vidére»** [Science and Art between Historical Memory and Digital Futures] is the natural evolution of creative, entrepreneurial experiences pursued in a variety of geographical and cultural backgrounds. It will provide continuity for interdisciplinary scientific and professional experiences that have evolved in different forms from as far back as **1949**.
To do research for producing innovative goods and services, "revealing" what exists in reality, but that the eye is unable to see [this is the meaning of the Latin word **«*intra*Vidére»]**, is the mission of the "Research-Institute".
Creativity and **innovation** are two of the basic "key words" of **«*intra*Vidére»**, following the wave of a consolidated tradition stretching back over 50 years. Along these routes we have always been at the forefront in terms of innovation. Leaders not only due to wide-ranging creative insight, in *starting-up* new areas of research, but also by fostering specific creative qualities and initiatives, at every stage of the processes of production, perfecting innovative procedures thanks to sophisticated technologies and devoted, avant-garde methodologies.

2.0.0 THE PHILOSOPHICAL APPROACH

«...Soil dynamics is far from a homogeneous body of knowledge, that there are major gaps and needed areas of research, and that some problems of practical importance have hardly been addressed whereas others of limited applicability are more thoroughly treated….»

Ralph B. PECK

2.1.0 Interdisciplinary Approach

The importance of the interdisciplinary approach is universally known and does not require any further explanation in this context. Nonetheless, in everyday practice, we directly experience the difficulties that interdisciplinary work entails. At the beginning of the third millennium we realize that we have become excellent specialists in specific fields, but have built up a system of Knowledge which not only makes it difficult for different disciplines to communicate with one another, but even raises barriers within the various disciplines themselves. Before the unity of any polyhedric reality, which requires a response that although multifaceted and segmented is likewise unitary, we always run the risk of unconsciously considering our sector more important than others and frequently continue to promote and develop studies in a monothematic manner. Research on geotechnics is by no means immune from these tendencies. So we tend more and more to become skilful specialists in analysis and lose sight of the need for synthesis. Conditioned by the certainties of our knowledge, we often commit quite glaring omissions or errors [Ciuffi *et al*., 1997].

2.2.0 Humanistic Culture and Scientific Culture: Two Cultures or One Culture?

Based upon the interdisciplinary approach above discussed, this very ancient question is an incorrect question.
In the present Research-work, sophisticated technologies and advanced scientific methods have come into communication with ancient documents exchanging questions and answers so as to understand the "how" and the "why", searching out secrets and revealing "inside knowledge": the profound meaning of ***intra*Vidére** has become an opportunity for synergy between Humanistic Culture and Scientific Culture, which when united in an efficacious synthesis become *Universal Knowledge*.

3.0.0 OUTLINE OF THE ENTIRE RESEARCH WORK [Initial Part of the Entire Research-work]

«*... Without Analysis the Synthesis is generic and vague, but without Synthesis the Analysis is a "brutishness"...*»
Jean GUITTON

3.1.0 Overview of the Research Activities [documents No. 1 and No. 2]

To plan the work programme, the *geotechnical team* has proposed an innovative, *interdisciplinary system*, in which the following seven main Thematic Areas have been selected:

HISTORICAL RESEARCH

REMOTE SENSING INTEGRATED ANALYSES

GEOMORPHOLOGY

GEOLITHOLOGY

INVESTIGATION PROGRAM

HYDROGEOLOGY

GEOTECHNICS AND FOUNDATION ANALYSES

The entire Research-work has been designed and implemented within a total period of about 3 years: three different, discontinuous principal phases [planned on the demands of the City Council (connected with the complex reconstruction activities) and the technical needs of the town planners], between May 1989 and March 1994.

The written general report [document No. 1] is divided into three parts.
The first part is devoted to the discussion of the main objectives, the general approach and the basic methods. Seven Thematic Areas are selected and described. Mentioned also is the Research-team.
The second part addresses the basic procedures and techniques adopted, within the different stages. Also emphasized are the synergies among the different Thematic Areas.
The last part contains the consulted bibliography.
The graphic document No. 2. shows the location of the area, together with the topographic parameters .

3.2.0 The Research General Flow-Chart

The general *flow-chart* [**Fig. 2**] is an essential compass within the entire Research-work. It shows the whole logic architecture, including the different stages and the links among the technical fields of the said Thematic Areas.
In order to organize a prompt, global vision for the reader, the activities and/or the documents are easy recognized by means of a specific color, each identifying the corresponding Thematic Area.
The results of the entire Research-work have been edited in fifty documents, which are mentioned in the Sub-Headings of the present paper, together with the corresponding number.

4.0.0 HISTORICAL RESEARCH [Thematic Area No. 1]

«*...The earth's crust is like a book whose pages recount the lessons of our past, though some of these pages have been lost because the writing has slowly faded, because the leaves have been brutally torn out or because builders have scorned to read them. The visible marks on her surface do not tell the whole story: there also exists a world of concealed forms…which is still largely undeciphered ….*»
Jean KERISEL

4.1.0 *Historical Research*: Methods Adopted and Historical Documents [document No. 3]

4.1.1 Main Activities. A detailed study about historical seismic events has been carried out, within the first stage. It should be noted that the proposed procedure has allowed to taken into account not only the seismic events centered on the Region in which Potenza is located, but also the effects [so frequently overlooked] due to "seemingly far earthquakes", occurring in other geographic areas, but causing localized damages also within Potenza urban area.
Performed in the next steps are the archive Researches of *Ancient Maps* and the selection and processing of Historic al Documents on *Foundation Works* of streets and superstructures.
Particular attention has been given to the restoration and reconstruction works following the different, past earthquakes.

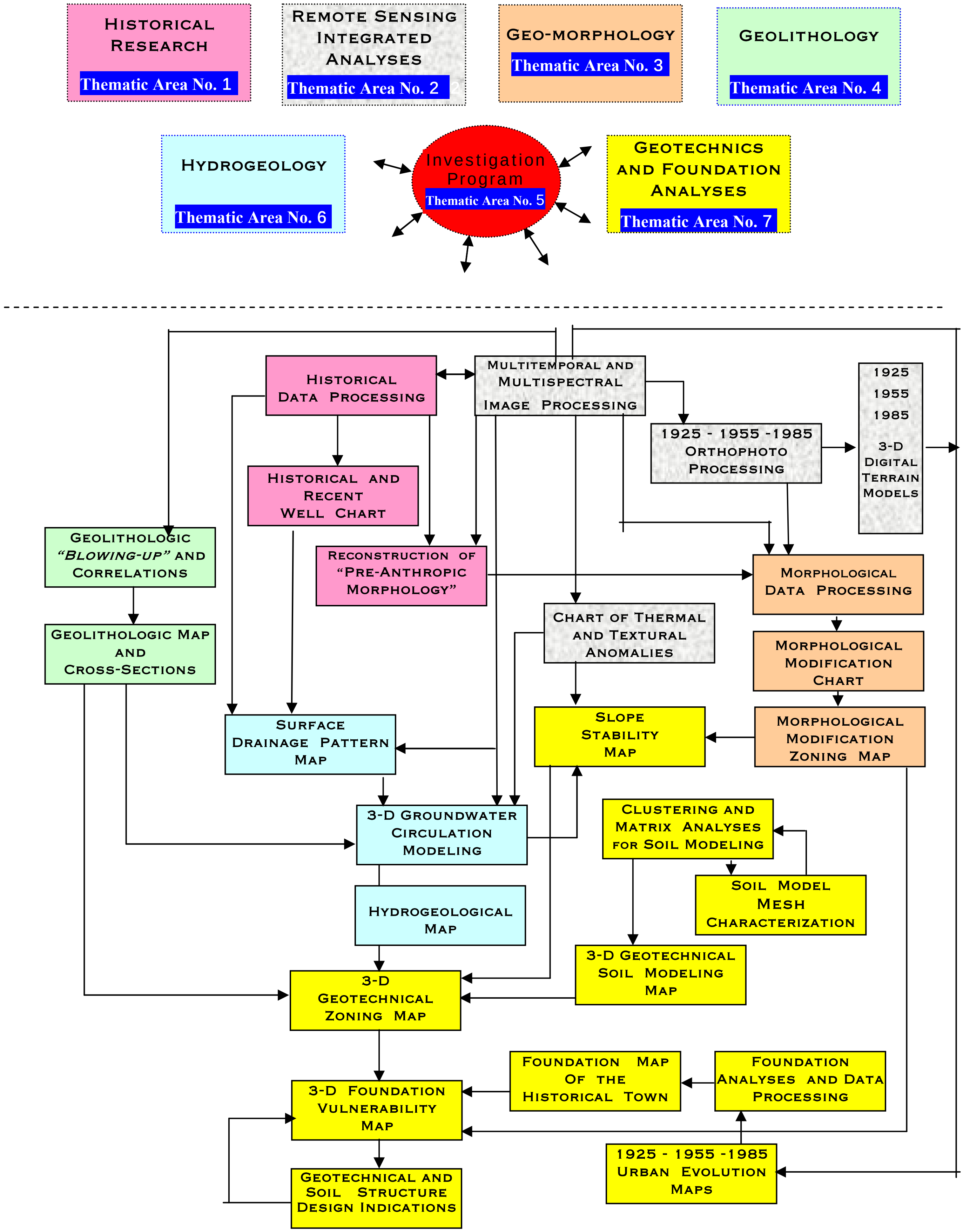


Fig. 2. Research General FLOW-CHART

4.1.2 Main Contents. Described in the first part of the written report are the methodology and the specific *flow-chart* of this Thematic Area.
The second part contains the synthesis of the sources consulted, together with a reproduction of the most interesting historical documents.
Described in the last part are the methods and the contents of the graphic results: *"Plans Comparative Analyses"* [document No. 4] and *"Historical and Recent Well Chart"* [document No. 5].

4.2.0 *Historical Research*: Plans Comparative Analyses [document No. 4]

4.2.1 Main Activities. The historical plan [1886] selected and processed has been digitized and geometrically corrected. Also the recent plan has been updated [1993] and digitized. Both plans have been geo-referenced in a *"Basic Geographical Information System"* to be superposed and studied.
The differences have been recognized, measured and analyzed.

4.2.2 Main Contents. In the graphic result are shown the processed historical plan [1886] together with the recent plan [1993].
The methodologies followed to prepare the said plans together with the comments are described in the said written report [document No. 3].

4.3.0 *Historical Research*: Historical and Recent Well Chart [document No. 5]

4.3.1 Main Activities. A number of historical documents [1880 – 1895], reporting graphic and numerical data on a complex system of wells, located on the hilly ridge, have been selected and studied.
In particular, the numerical values of each "historical well", consisting of the measured depth of the water table, have required a specific normalization, together with the topographic data.
Implemented has been also a parallel study of the wells discovered during the restoration works [analyzed for each single building, within the historical town] related to the 1980 earthquake and executed between 1982 and 1990. The data have been collected, classified and mapped, in the same chart.

In order to use all the results for the hydrogeologic studies, a further analysis has been carried out to correlate the processed data of the "historical wells" [together with the corresponding depth of the water table] and the parameters of the "recent wells".

4.3.2 Main Contents. In the chart, represented in the said *"Basic Geographical Information System"*, are mapped the "historical wells" together with the "recent wells".
Numerical indications of the depths of the water table are also shown.

5.0.0 REMOTE SENSING INTEGRATED ANALYSES [Thematic Area No. 2]

«*...There is nothing mysterious that does not become apparent, and vice-versa whatever is apparent hides a mystery within itself….*»

Pavel FLORENSKIJ

5.1.0 *Remote Sensing Integrated Analyses*: Methods followed and Image Processing [document No. 6]

5.1.1 Main Activities. *Remote Sensing Integrated Analyses* represent a crucial and basic tool for the entire Research-work.
Integrated Processing of *Multispectral and Multitemporal Images* have been planned and implemented. Sophisticated analyses have been carried out collecting and processing data generated by different platforms: Satellite, Aerial, Land platforms.

The Satellite data have been acquired by two distinct platforms: SPOT-2 Satellite and ERS-1 Satellite.
The first one has been launched in January 1990 and has been placed in a sun-synchronous orbit, at an altitude at equator of about 822 km. The spectral bands have the following characteristics: 1 *panchromatic band* [spectral range = 0.50-0.73 µm; resolution = 10 m]; 3 *multispectral bands* [spectral ranges = 0.50-0.59 µm, 0.61-0.68 µm, 0.79-0.88 µm; resolution = 20 m].
ERS-1 Satellite has been launched in July 1991 and has been ESA's first sun-synchronous polar orbiting remote sensing mission, operated until March 2000. To meets its mission objectives, **ERS**-1 has been placed in a near-polar orbit at a mean altitude of about 780 km with an instrument payload consisting of an Active Microwave Instrument comprising a **SAR,** *Synthetic Aperture Radar* [operating in image and wave modes] and a Wind Scatterometer; a Radar Altimeter; an Along Track Scanning Radiometer; a Precise Range and Range-rate Equipment; and Laser Retro-reflectors.

The following 4 *multitemporal* groups of Aerial Photographs have been selected and processed: 1955, 1974, 1980, 1985.
In addition, an important and unique "old document" has been discovered [within the *Historical Research*] and studied: the Aerial Photo taken acquired, "by chance" , in 1925.
It is the first Aerial Photo of Potenza and it is one of the most ancient Aerial Photographs, worldwide. Additional processing activities have been needed to study this 1925 Aerial Photo together with the other groups.
A complex effort has been performed to achieve a propaedeutic basic goal: the exact superposition among the different Multitemporal Aerial Photographs.
For this purpose, each Aerial Photo selected has been digitized and geo-referenced in the mentioned *"Basic Geographical Information System"*, after application of geometric/radiometric corrections. The correction process has removed image distortions and has re-sampled the imagery to a uniform ground sample distance and a specified map projection.

Data generated by Land Platforms have been acquired by a mobile laboratory and consist of two distinct techniques: *"Multitemporal Photography in Infrared False Color"* and *"Multitemporal Thermographic Monitoring"*. Both types of analysis are based on the use of what are known as "passive" sensors, i.e. sensors which record what is spontaneously emitted by the object. Eight topographic locations [G3 and G6 are shown in **Fig. 3**.] have been planned for the mobile laboratory monitoring. Eight groups of multitemporal data have been acquired in various seasons, during the day and the night.

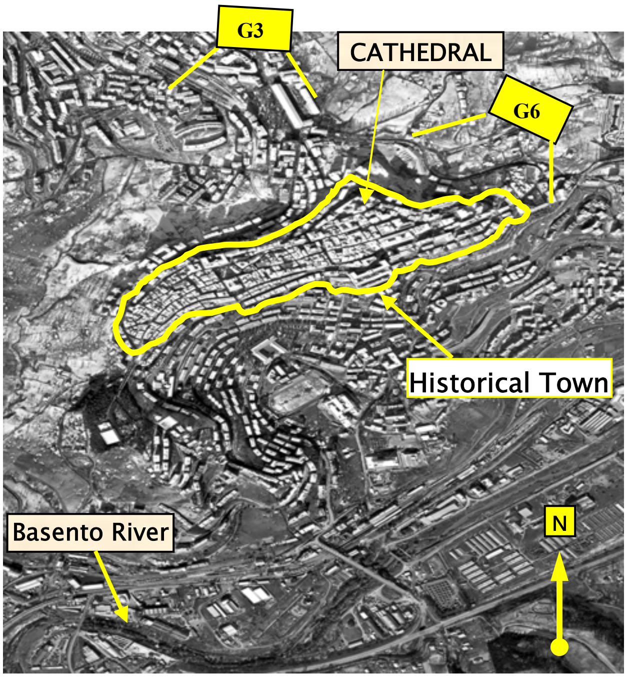


Fig. 3. *1980 Potenza Aerial Photo Twelve Days after the Great Earthquake*

"Multitemporal Photography in Infrared False Color". This type of photography is similar in concept to the common photography, save for a different spectral band, which in this case is between 0.5 and 0.9 µm. The colors appear different from those shown by the objects in nature.

"Multitemporal Thermographic Monitoring". These measures are based on recordings of electromagnetic wave fluxes spontaneously emitted by bodies in the thermal infrared band [comprised in this case between 2.0 and 5.6 µm]. These fluxes are converted into images that represent, under different environmental conditions, thermal maps of the object studied. The possibility of monitoring on a continuous basis, calculating the relative parameters, the energy exchanges, occurring between an object and the environment in which it lives, is fundamentally important for the detection of discontinuities and differences within the object itself.

All the information obtained and calculations performed have been reprocessed in a unitary context, on the basis of specific methodologies, mostly of an innovative type and in some cases specially developed by the Research-team. Where necessary, following an iterative procedure, the basic calculations have been reprocessed, using parameters compatible with different types of analyses and procedures.
All the images resulting from the analyses briefly described above have been subjected to appropriate analog and/or digital processing. The calculations performed have been of various types, ranging from the most common to the most complex [filtering, derivation and integration, slicing, etc.] and sophisticated [calculations using "cluster analysis" algorithms or involving the conversion of an image into its Fourier representation], right up to the construction of numerical models. The results of these calculations have allowed the greatest possible amount of knowledge to be "extracted" from the images in relation to specific objectives [Ciuffi *et al.*,1997].

5.1.2 Main Contents. Described in the first part of the written report are the methodology and the specific *flow-chart* of this Thematic Area.
The second part describes and discusses the image processing activities, together with the procedures, the most interesting algorithms and the results. Particular emphasis has been given to the synergies and the links developed among the seven Thematic Areas.
Described in the last part are the methods and the contents of the graphic results: *"1925 – 1955 – 1985 Orthophoto Processing "* [documents No. 7, No. 8, No. 9] and *"Chart of Thermal and Textural Anomalies "* [document No. 10].

5.2.0 *Remote Sensing Integrated Analyses*: "1925 – 1955 – 1985 Orthophoto Processing" [documents No. 7, No. 8, No. 9]

5.2.1 Main Activities. Specific Image Processing of *1925, 1955, 1985 Aerial Photographs* have been carried out to generate *Digital Orthophotos.* In these products, image displacements caused by camera tilt and terrain relief have been removed. *Digital Orthophotos* combine the image characteristics of a photograph with the geometric qualities of a map and can be used in numerous *"Basic Geographical Information System"* applications either alone or in combination with other digital data. It is important to emphasize that, in this case, the term *Orthophoto* is used in a particular and very original way. In fact, the isohypses, superimposed on the processed Aerial Photos, are the result of a very innovative procedure focused to reconstruct a reliable hypothesis of the *"original pre-anthropic morphology"* of the ancient hilly ridge. This advanced result has been based on the strong synergy between the study of the spectral characteristics of different images and a devoted image processing of the *Multitemporal Aerial Photographs*.

5.2.2 Main Contents. The three graphic documents [documents No. 7, No. 8, No. 9] show the three processed *Orthophotos* [1925 – 1955 – 1985]. The superimposed original isohypses are easily recognizable in red [**Fig. 4**]. Also plotted [in yellow] are the *"Linear Features"*, later discussed in this paper. The methods followed to prepare the said plans together with the comments are described in the written reports [documents No. 6 and No. 44].

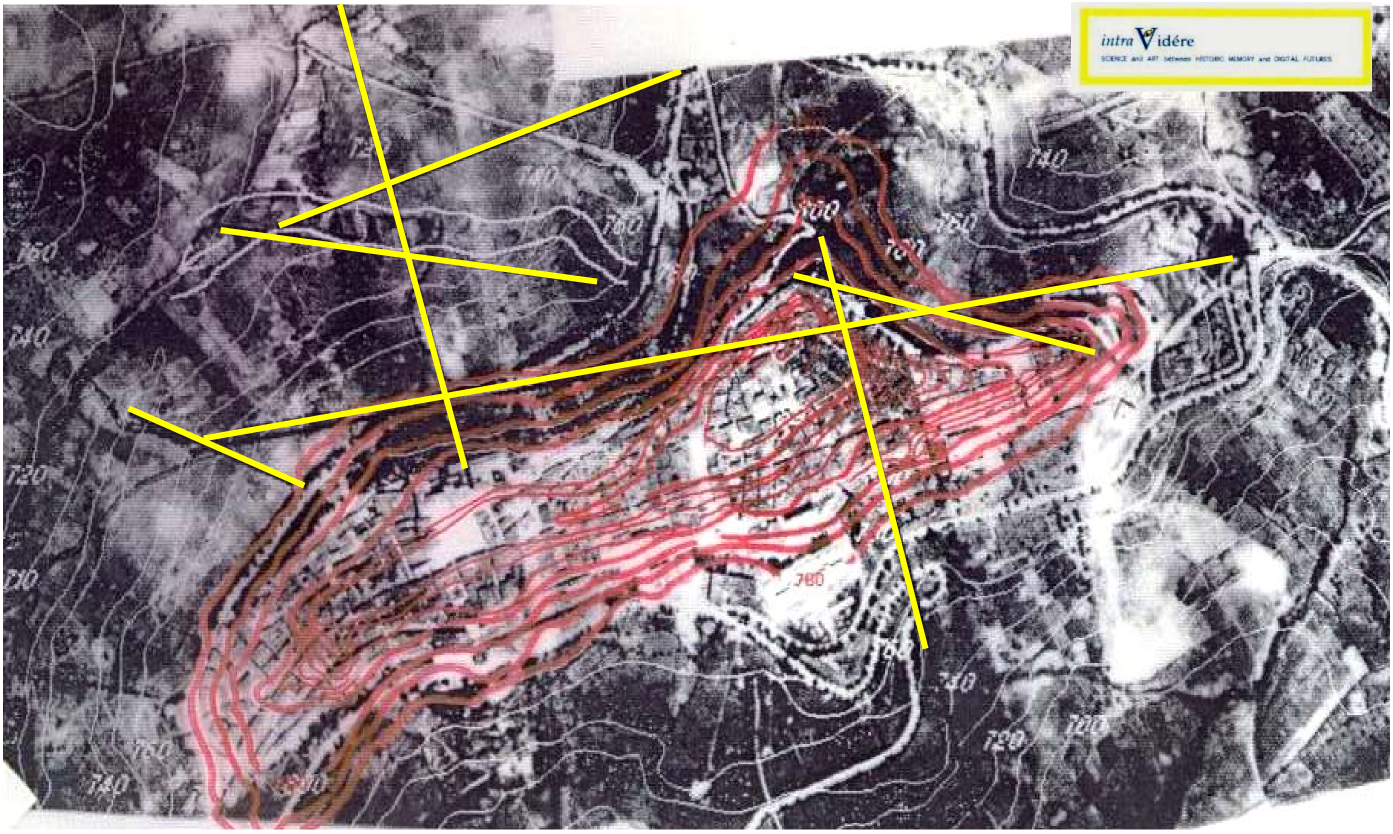


Fig. 4. 1925 "Ortophoto" Processing

Fig. 5. 3-D 1925 Digital Terrain Model

5.3.0 *Remote Sensing Integrated Analyses*: "Chart of Thermal and Textural Anomalies" [document No 10]

5.3.1 Outline of Main Activities. Sophisticated Image Processing of the eight *"Multitemporal Thermographic Monitoring"* groups have been implemented. It deems opportune to remind that each group contains the data produced by an exact "topographic location" [of the mobile laboratory], planned for monitoring soil parameters and land use features.
The following two distinct processing data groups [**Fig. 3**] have been selected to be shown in the *"Chart of Thermal and Textural Anomalies":* **G3** [topographic location relative to the northern slope of the hill] and **G6** [topographic location relative to the "clay quarry"]. In fact, the contribution given by the results of the said two groups to the entire Research-work have been very decisive, as summarized in the following lines. Moreover, within both groups, specifically devoted procedures have been devised.
The processing stages of the **G3** data have allowed a zoning of the northern slope, based on the different levels of water saturation. In particular, two areas have been selected to be further processed, "blowing-up" in an even smaller scale. Within the said areas, additional analyses have been carried out. It has been possible to detect and to zone other sub-areas, identifying hydrogeological features.
The **G6** group is located in front of an old "clay quarry", in the northeast side of the hilly ridge. The quarry, which is a part of the hill itself, was active until the mid-1900s. The ruins of an old brick-kiln, located in the same site of the quarry, are still visible. The material of the quarry is the so-called "blue clay". This is a stiff cohesive blue-grey soil [the permeability is very low], typical of the city of Potenza [see also paragraph 7.0.0].
The laborious processing stages [in many cases repeated, as "convolution filtering"] have allowed a recognition of "strike and dip" of blue-clay formation.
The advanced results of both groups have been very useful tools to achieve one of the most important goal of the Research**-**work: the construction of the *"shallow 3-D groundwater circulation modeling"* which will be discussed in the next paragraphs, simply indicated "***3-D groundwater circulation modeling".***

5.3.2 Main Contents. The graphic document titled *"Chart of Thermal and Textural Anomalies"* contains the results of the thermographic processing data, corresponding to the following two groups: **G3** [northern slope of the hill] and **G6** [clay quarry].
The methods followed to prepare the said document, together with the results and the comments, are described in the written report [document No. 6].

6.0.0 GEOMORPHOLOGY [Thematic Area No. 3]

«...The same regions do not remain always sea or always land, but all change their conditions with time ….»

ARISTOTELE

6.1.0 *Geomorphology*: Methods Adopted and Data Processing .[document No. 11]

6.1.1 Main Activities. The synergies between Historical Research, Remote Sensing processing and Geomorphologic studies have been very strong, as just said.
As regards, in particular, the present Thematic Area, it has to be noted that the study has not been limited to describe and to analyze the geomorphologic characteristics. In fact, the geomorphologic research has had the following larger goal: to detect and quantify the areas of the hilly ridge where morphological modifications have been occurred, in the past.
To achieve this goal, the profiles of each street [main streets and "decumans"; in total 53 streets], within the hill, have been studied. To quantify the morphological modifications, numerical and graphic correlations have been implemented among the morphological aspects of three periods: the earliest times ["Pre-Anthropic Morphology"], the ancient time ["Ing. Rosi Profiles"], the present time [Recent Topographic Map].
The "Pre-Anthropic Morphology" has just been discussed in sub-paragraph 5.2.1. The so-called "Ing Rosi Profiles" are historical documents consisting of the topographical data drawn, in 1883, by Rosi [civil engineer], for designing the first "city sewer system".

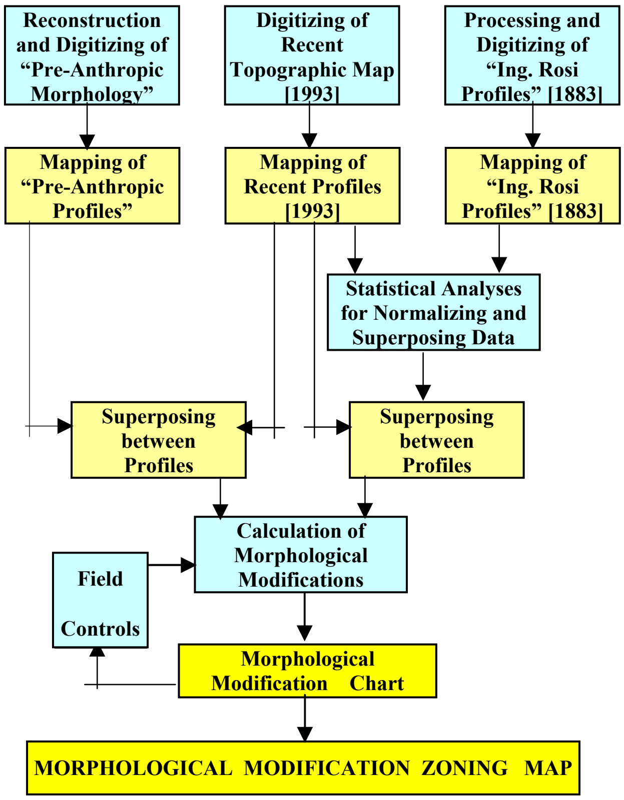


Fig. 6. *Geomorphologic Flow-Chart*

6.1.2 Main Contents. Reported in the first part of this written document No.11 is a geomorphologic description.
The second part contains the methodology followed and the specific *flow-chart* [**Fig. 6**] of this Thematic Area.
Described in the last part are the methods and the contents of the graphic results: *"Morphological Modification Profiles"* [documents No. 13 (via Pretoria Profile), No. 14 (Strada Estramurale), No. 15 (Via del Popolo)], *"Morphological Modification Chart"* [documents No. 16], *"Morphological Modification Zoning Map"* [documents No. 17].

6.2.0 *Geomorphology*: Calculations [document No. 12]

6.2.1 Main Activities. All the values have been processed to make morphological data comparable. Very problematic has been the interpretation of the altimetrical values adopted by Rosi. A problem has been also the correlation between old and current toponymy. A statistical analysis "ad hoc" has been developed to determinate the correction for normalizing the absolute altitudes.
In this way, it has been possible to achieve the superposition among the different chronological profiles, street by street. Morphological changes have been, then, recognized, quantified, classified and grouped.

6.2.2 Main Contents. Reported in this written document are the calculations carried out for normalizing the data and comparing the chronological profiles, street by street.

6.3.0 *Geomorphology:* Morphological Modification "Via Pretoria" – "Strada Estramurale" – "Via del Popolo" [documents No. 13, No. 14, No. 15]

6.3.1 Main Activities. After processing all the values, the superposition among the different chronological profiles, street by street, has been drawn. The selected profiles of the most important streets are shown in these graphic documents: each street is about 2 km in length.

6.3.2 Main Contents. These graphic documents contain the superposition among the different chronological profiles, corresponding to the three main streets of the hill, oriented on a N.E. – S.W. axis.
The methods followed to prepare the said documents, together with the comments, are described in the general written report of this Thematic Area [document No. 11].

6.4.0 *Geomorphology:* Morphological Modification Chart [document No. 16]

6.4.1 Main Activities. The results of the calculations developed [see paragraph 6.2.0] have been graphically summarized on this chart. The following six classes selected [**Table 1**] have been drawn on a plan, along each street.

Table 1. Morphologic Modification Classes

Modifications: Landfills [values and graphics]	*Modifications:* Excavations [values and graphics]
Less than 2.00 m • • • •	Less than 2.00 m • • • •
Between 2.00 m and 4.00 m – – – –	Between 2.00 m and 4.00 m – – – –
Higher than 4.00 m ▬ ▬ ▬	Higher than 4.00 m ▬ ▬ ▬

It has been possible to obtain an overview of the morphological modification occurred, along the 53 streets of the historical town.

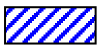
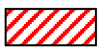
6.4.2 Main Contents. The plan [**Fig. 7**] shows the different colors and graphic symbols identifying, along each street, the stretches associated to one of the said classes.
The calculations are contained in the specific written report [document No. 12], described in the paragraph 6.2.0.

6.5.0 *Geomorphology:* Morphological Modification Zoning Map [documents No. 17]

6.5.1 Main Activities. The quantified and classified Morphological changes [plotted along each street on the previous map] have been further processed and, finally, grouped, for zoning the hilly ridge "morphological history".

6.5.2 Main Contents. The zoning map [**Fig. 8**] shows the selected four classes, described in the following table.

Table 2. Morphologic Modification Zoning Classes

Morphologic **ZONING Classes**	*Morphologic Modification* **ZONING Description**
	Zones in which Excavations ≤ **4.00m** are Prevalent [Involve parts of streets altogether longer than 70%]
	Zones in which Excavations ≥ **4.00 m** are Prevalent [Involve parts of streets altogether longer than 70%]
	Zones in which Landfills ≤ **2.00 m** are Prevalent [Involve parts of streets altogether longer than 70%]
	Zones in which Landfills ≥ **2.00 m** are Prevalent [Involve parts of streets altogether longer than 70%]

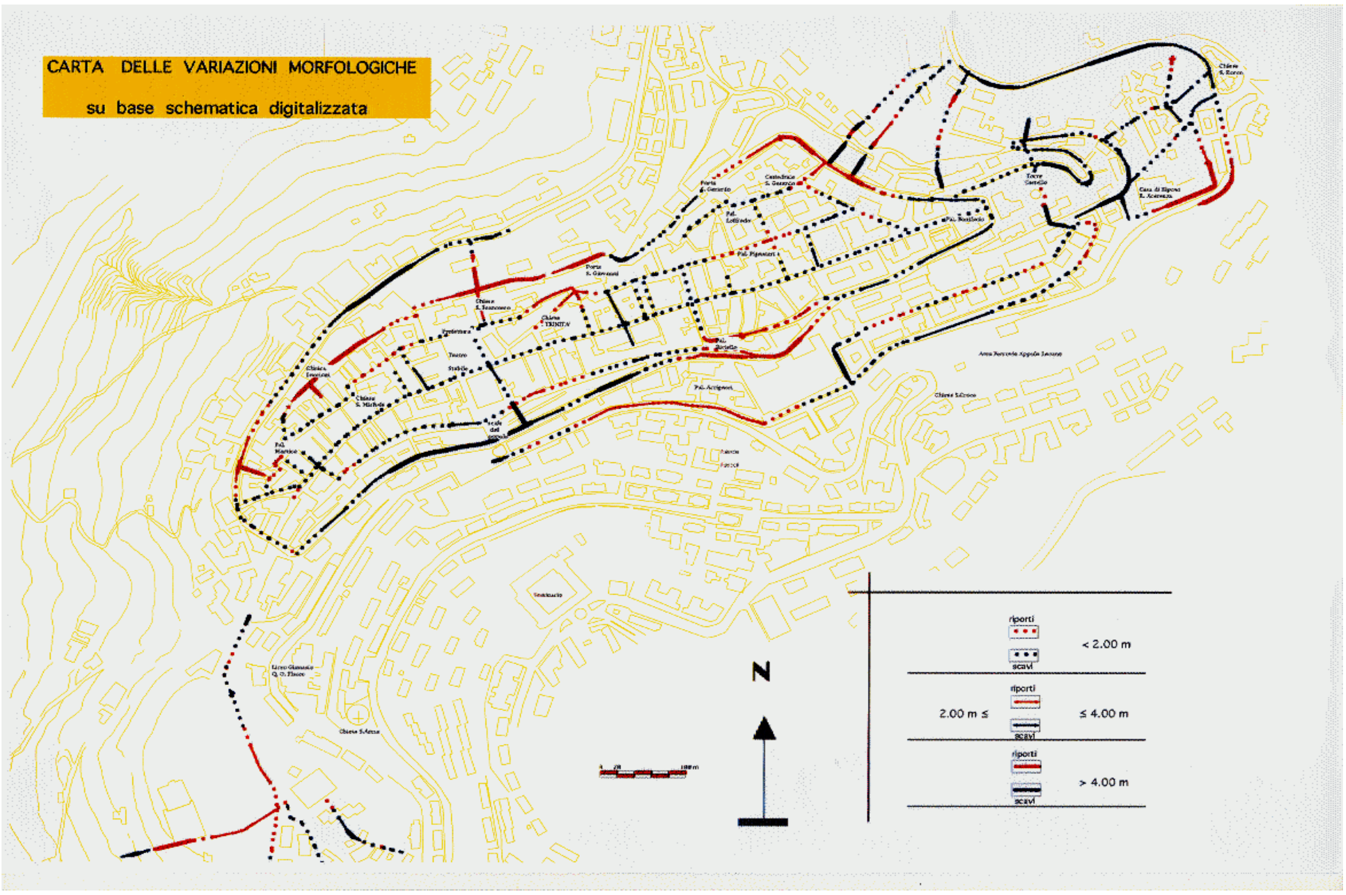


Fig. 7. *Morphological Modification Chart*

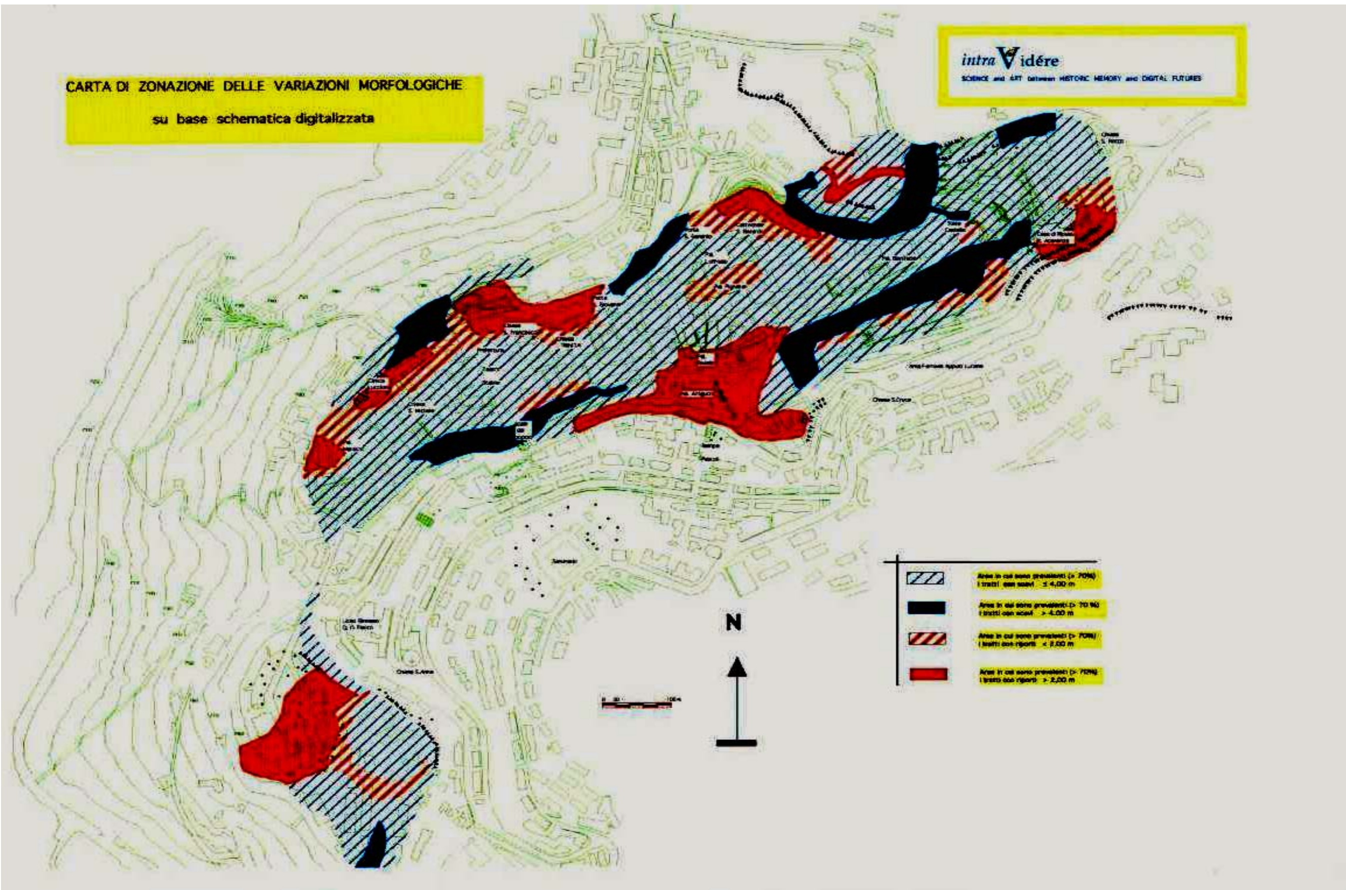


Fig. 8. *Morphological Modification Zoning Map*

7.0.0 GEOLOGY [Thematic Area No. 4]

«...It is a sin…to tear…our common mother…You ask me to dig for stone! Shall I dig under her skin for her bones? Then when I die I cannot enter her body to be born again…»

SMOHALLA

7.1.0 *Geology:* Methods Adopted [document No. 18], Geolithologic Map [document No. 19], Geolithologic Cross-Sections [document No. 20],

7.1.1 Main Activities. In the present paper, it may be interesting to mention the original approach developed, in good accordance with one of the strategic objectives of the entire Research-work: to study the behaviour and to characterize the soil properties of the shallow layers of the hilly ridge on which is located the historical town.
In fact, it is important to remind that the buildings of the said historical town [mostly, ancient masonry structures] have, in general, shallow foundations.
To achieve this goal, the geolithological study has been designed, in a very detailed scale, "zooming in" on the shallow layers of the hilly ridge.
An analysis of the existing geolithologic studies [regarding the urban area of Potenza] has been developed. It should be stressed that all the existing studies performed have observed the hilly ridge by "very far – or far – points of view": studies at regional scale and at urban scale. For this reason, the said studies [mostly, excellent works] have considered a geo-lithologyc profile of the hilly ridge in a more schematic way.
On the contrary, in the present study, it has been developed a "micro-geolithologic analysis" of the superior layers, investigating "inside" the always recognized levels. The following figure [**Fig. 9**] summarizes the results of the comparative analyses performed. The figure appears explicative.
Two levels have been screened within the "Clayey Lithofacies": **C2** and **C1**. The first one represents the "Overconsolided Blue-Grey Clays", just discussed in the sub-paragraph 5.3.1 The upper stratum **C1** represents the sandy facies of the clays, characterized by sandy-silty and silty-sandy levels.
Proceeding in the same manner, the stratum **B** has been analyzed in more detail, identifying, gravel embedded in a sandy-silty matrix, with conglomerates more present at the top.
Also thoroughly examined, by "blowing-up", have been the "Surface Weathering Covers". Two different layers have been screened within the said "Recent Covers": **Ab** and **Ac.** Both the layers are covers consisting mostly of chaotic materials and landfills, with an organic component. **Ab** identifies the *"Covers above the Sandy-Gravely Complex"*, in which the coarse soils are prevalent. On the other hand, **Ac** represents the *"Covers above the Silty Complex"*, in which the fine-grained components are prevalent, mixed with peaty levels.
It should be stressed that the two *"Cover"* typologies recognized have been further processed and divided into the

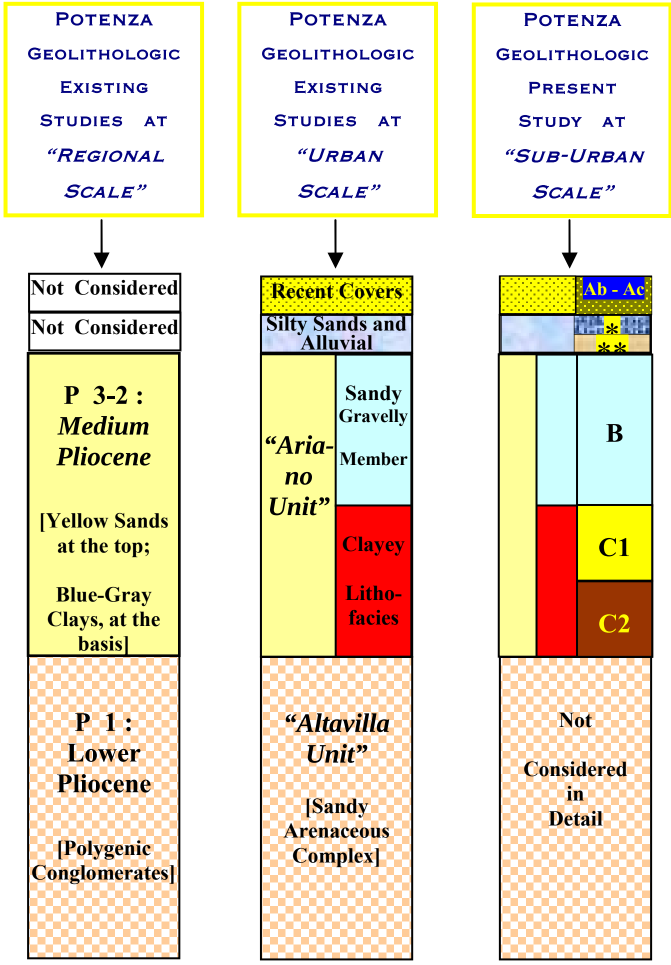


Fig. 9. Comparative Analyses among Geolithologic Models

following sub-typologies:

Ab1 =*"Covers"* $\geq$ **5.00** m **Ab2** =*"Covers"* $\leq$ **5.00** m
Ac1 =*"Covers"* $\geq$ **5.00** m **Ac2** =*"Covers"* $\leq$ **5.00** m.

It has to be added that, in a number of cases, the thickness of the said *"Covers"* ranges around 10.00 m.
Finally, it has to be noticed that the symbols * [**D** = Colluvium and Detritus] or ** [**L** = Grey and Greenish Silts] indicate formations not present within the area studied in detail.

7.1.2 Main Contents. The written report [document No. 18] is devoted to the discussion of the methodologies, the procedures and the results. Also described are the procedures followed for constructing the graphic documents below mentioned.
The *"Geolithologic Map"* [document No. 19] shows the zoning [within the historical town] of the different areas, screened on the basis of geolithologic features. Also plotted are the *"Linear Features"* [Faults and/or Fractures] recognized, important for the *fracture density* analysis, later discussed in this paper.
The *"Geolithologic Cross-Sections"* [document No. 20] show the two cross-sections constructed.

8.0.0 INVESTIGATION PROGRAM
[Thematic Area No. 5]

«*...If I were to draw any moral from my talk it would be to avoid going to a catalogue when you have a special or unusual testing need…Be very cautious about buying things of the shelf. It is much better to try to make the apparatus if you can and you're more likely to have success.*»

A. W. BISHOP

8.1.0 *Investigation Program*: "Overview of Methods of Investigation", "Site Location" [documents No. 21 and No.22]

8.1.1 Main Activities. In the preliminary stage, a large geotechnical data collection activity has been planned and developed. The soil investigations performed in the past, at Potenza urban area, have been searched, collected, analyzed and selected. Thus, it has been initiated the construction of a geotechnical urban database.

The selected data have been useful for focusing the design of the investigation program, at the beginning of the entire Research-work. The high level of flexibility has been the philosophy of the said program. For this reason, only the basic lines have been designed in detail, together with a number of different possible hypotheses, just outlined .

In fact, the interdisciplinary approach of the entire Research-work has required an investigation program very advanced and rigorous, but, at the same time, being able to follow the needs, on he basis of the evolution of the different Thematic Areas. Therefore, the implementation of the investigation program has been developed step by step, according to the partial results, gradually achieved.

The whole investigation activity has been carried out in ten different stages, within the three phases [see sub-paragraph 3.1.0] of the entire Research-work.

8.1.2 Main Contents. Described in the written document [No. 21] is an overview of the whole investigation activity Also discussed are the documents containing the results of the investigation techniques performed.

The site location of each test is mapped on a general plan [document No. 22].

8.2.0 *Investigation Program*: Data Processing [document No. 23]

8.2.1 Main Activities. The practice implementation of the different stages of the Investigation program has not been always an easy work. It is well known that the investigation activity, within a historical town, is a very difficult activity. In the present case history, very problematic has been the presence of an intricate network of buried [old and recent] "public utilities", not easily identifiable: electrical and telephone systems, gas pipes, aqueducts, sewer systems, etc. In addition, in a number of zones, the traffic has interfered with the investigation activities.

As regards the basic approach in data processing, it has to be noted that each single test, within a specific typology, has been cheeked [taking into account also the environmental conditions] to be validated. Each set of tests has been analyzed and normalized, before data processing.

It is impossible, in the present paper, to discuss the different investigation techniques adopted, even if a limited part is selected. In fact, a large space is needed. On the other hand, it has been chosen to reserve more space for other Thematic Areas.

For this reason, it is simply described, in the following table, a list of the different tests and analyses implemented within the investigation program. It can be seen that the investigation activities have been divided into three groups to facilitate an overview: *"Common Tests"*, *"Advanced in situ Tests"*, "*Innovative non Destructive Analyses"*. The symbol [No.], in the third column, indicates the number of the document containing the corresponding results.

It should be noted that two typologies of analyses ["*Thermographic Monitoring"* and "*Multitemporal Photography in Infrared False Color"*] associated to the said third group are important parts of the Thematic Area *"Remote Sensing Integrated Analyses"* and, consequentially, have been discussed in the sub-paragraph 5.1.1.

It may be appropriate to conclude this paragraph, adding only a short mention about the investigations named *"In Situ Rheological Tests"*. They consist of the so called *Relaxation Tests*, which have given an interesting contribution in investigating the ***degree of interlocking*** and recognizing soils also characterized by ***dilatancy*** [Whitman, 1979]. The procedure of these sophisticated in situ tests has been devised by the Research-team.

Table 3. Investigation Program: List of Tests Implemented

TEST GROUP	INVESTIGATION TECNIQUE	No.
Common Tests	**Cone Penetration Tests**	**25**
Common Tests	**Wave-Propagation Tests**	**26**
Common Tests	**Electrical Resistivity tests**	**27**
Common Tests	**Borings together with Laboratory Tests**	**28**
Advanced in Situ Tests	**Borehole Shear Tests**	**29**
Advanced in Situ Tests	**Pore Pressure In Situ Measures**	**30**
Advanced in Situ Tests	**In Situ Rheological Tests**	**31**
Innovative non Destructive Analyses	**Thermographic Monitoring**	**24**
Innovative non Destructive Analyses	**Multitemporal Photography in Infrared False Color**	**24**
Innovative non Destructive Analyses	**Multifrequency Radar Analyses**	**32**

8.2.2 Main Contents. The investigation report [document No. 23] contains, for each typology of analysis, the description of the tests carried out, the methodologies adopted and a discussion on the results obtained.
It may be opportune to remark that the results of the ten typologies of analyses implemented are reported in the documents numbered in the table.

9.0.0 HYDROGEOLOGY [Thematic Area No. 6]

«…*Water is the Blood and the Lymph of the World...* »
LEONARDO da VINCI

9.1.0 *Hydrogeology*: Methodologies and Data Processing [document No. 34]

9.1.1 Main Activities. The synergies between Hydrogeologic Studies, Historical Research and Remote Sensing Data Processing have been decisive, as just emphasized, also discussing other Thematic Areas.
The Hydrogeologic Research has been developed following two different lines, distinct but strongly interactive:
[i] "study of the surface drainage pattern";
[ii] "study of the *groundwater circulation model*".

The study of the *"surface drainage pattern"* within an urban area – and in particular, within a historical town – requires the knowledge of several "invisible" elements buried or quite lost. For this reason, the objective has been to detect the said elements and to study them, together with the very limited visible flowing, for reconstructing the said "surface drainage pattern" of the hilly ridge.

It has been emphasized that the reconstruction of the *"shallow groundwater circulation model"*, within the hilly ridge, has been one of the basic results of the entire Research-work. The study has been developed following different stages, selecting and processing the results generated by distinct Thematic Areas.
The said different stages can be summarized, as follows.
[i] The first step has been the analysis of *fracture density*, based on the "*Linear Features"* [as determined in the paragraph 7.0.0] processing.
[ii] In the second stage, a detailed study of permeability has been conducted. Each lithological class has been associated to one of the two main groups of permeability: ***"primary permeability by porosity"***, ***"secondary permeability by fracturing"*** .
[iii] A permeability matrix has been created ad hoc. Five classes of permeability have been determined.
[iv] The *Remote Sensing Integrated Analyses* have allowed the determination of the zones of ***water storage*** and the areas of ***water recharge***, together with the *preferential groundwater flow directions* and the ***sheet*** *water flow directions* [Marcolongo, 1987].
Contemporaneously, a further specific process has allowed the recognition of "strike and dip" of blue-clay formation, characterized by very low permeability [as discussed in the paragraph 5.3.1].
[v] The results of the analyses above described have been further processed all together, on the basis of a devoted iteration process implemented for constructing the "***3-D groundwater circulation modeling"*** [**Fig.10**].

9.1.2 Main Contents. The first part of the written document [No. 34] addresses an overview of the Thematic Area, together with a description of the general methodologies and the specific procedures adopted.
The second part describes methods, data processing and contents [together with the comments] of the graphic results: *"Surface Drainage Pattern Map"* [document No. 35] and *"Hidrogeological Map with the 3-D Groundwater Circulation Model"* [document No. 36].

9.2.0 *Hydrogeology*: "Surface Drainage Pattern Map" [document No. 35]

9.2.1 Main Activities. The activities have been focused, mainly, to discover and to recognize, within the hilly ridge, the hydrologic elements buried or quite loss. Essential, for this goal, has been the contribution of the Historical Research, as mentioned in the previous paragraph No. 4.0.0. The interaction between historical documents processing and *Remote Sensing Integrated Analyses* has allowed to detect and to recognize the said "invisible" hydrologic elements and to organize them in a coherent hydrogeologic system.
Thus, it has been possible to reconstruct the *surface drainage pattern*, even if conditioned by different anthropic activities.

9.2.2 Main Contents. The map shows the reconstruction of the *surface drainage pattern* of the hilly ridge, with the gullies and other discovered hydrologic elements.
The said *drainage pattern* is slightly more diffused on the south slope: the *preferential run-off directions* are oriented on a N.E. – S.W. axis, flowing into the Basento valley. On the other hand, the north slope is characterized by a *drainage pattern* less diffused but more concentrated. This is in good accordance with the presence of the ***"paleo groundwater-flow direction"*** which is discussed in the next paragraph.

9.3.0 *Hydrogeology*: Hydrogeological Map and 3-D Groundwater Circulation Model [document No. 36]

9.3.1 Main Activities. The discovery of a hydrogeologic feature on the N.E. slope has been a very interesting and unexpected result. The said hydrogeologic feature is a so-called ***"paleo groundwater-flow direction"***, oriented on a N.E. – W. axis.
In any case, the activities have been described in the previous sub-paragraph 9.1.1. In addition, it seems interesting only to describe the five classes of permeability, determined. The following table [**Table 4**] summarizes the results of the permeability matrix processing, determining the said five classes.

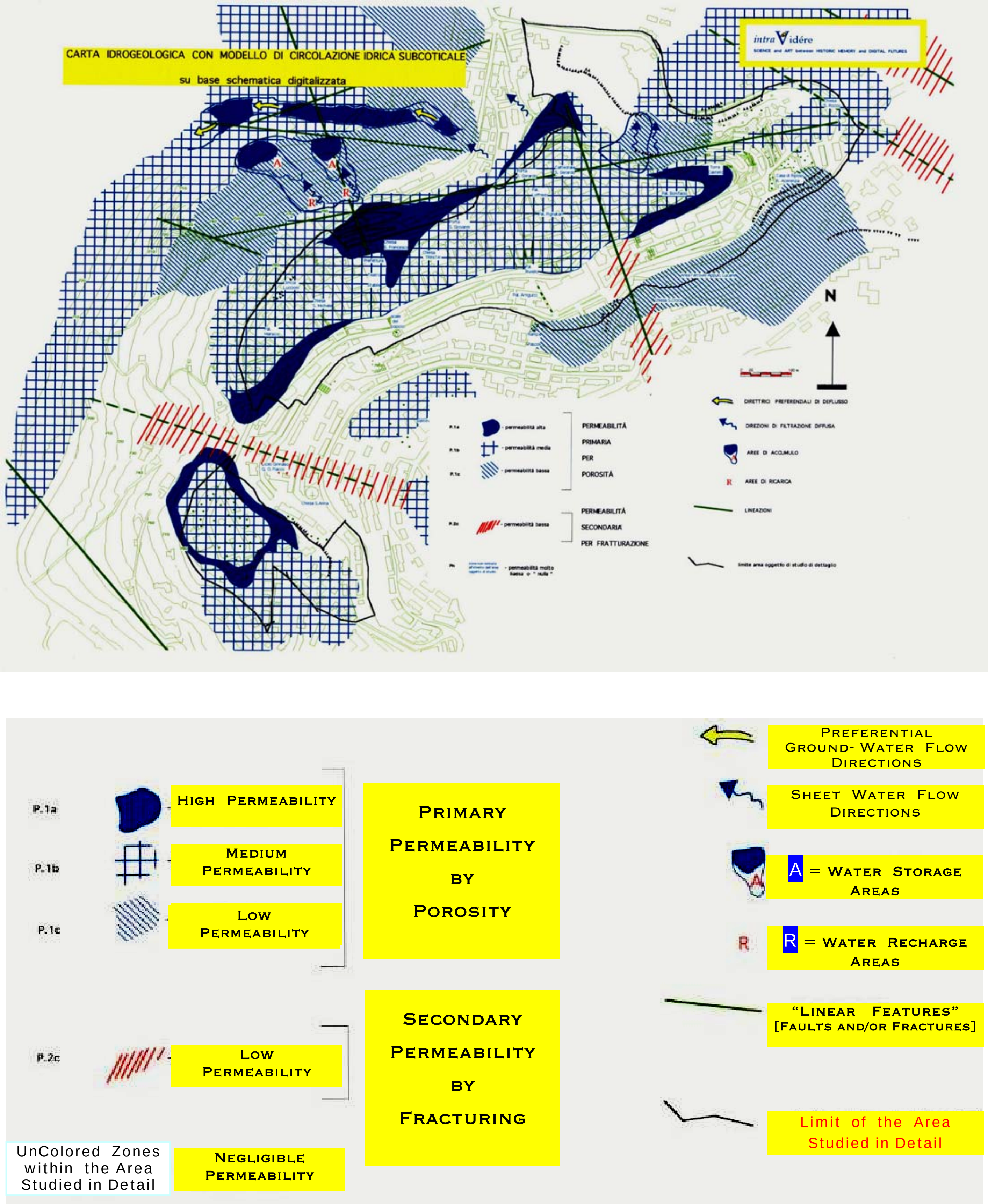


Fig. 10. *Hydrogeologic Map and 3-D Groundwater Circulation Modeling*

Table 4. Classes of Permeability by Porosity and Fracturing

CLASSES OF PERME-ABILITY	PERMEABILITY LEVEL DESCRIPTION	LITHOLOGIC CLASSES **[See Sub-paragraph 7.1.0]**	FRAC-TURE DENSITY
P. 1a	**HIGH by Porosity**	**B** [Gravel embedded in a Sandy-Silty matrix]	
P. 1b	**MEDIUM by Porosity**	**Ab2** ["Surface Weathering Covers" (h < 5.00m) above the Sandy-Gravely Complex]	
P. 1b	**MEDIUM by Porosity**	**Ab1** ["Surface Weathering Covers" (h > 5.00m) above the Sandy-Gravely Complex]	
P. 1b	**MEDIUM by Porosity**	**D** [Colluvium and Detritus]	
P. 1b	**MEDIUM by Porosity**	**C1** [Sub-Outcropping Sandy Facies of the Clays]	
P. 1c	**LOW by Porosity**	**Ac1** ["Surface Weathering Covers" (h > 5.00m) above the Silty Complex]	
P. 1c	**LOW by Porosity**	**L** [Grey and Greenish Silts]	
P. 2c	**LOW by Fracturing**	**C2** [Sub-Outcropping (depth < 5.00m) Overconsolidated Blue Clay]	**High**
P. n	**Very LOW or NEGLIGIBLE**	**C2** [Sub-Outcropping (depth < 5.00m) Overconsolidated Blue Clay]	**Low**

9.3.2 Main Contents. The most important elements of the "***3-D groundwater circulation modeling***" are plotted on the map. The described five classes of permeability have been zoned. Clearly identified are the zones of ***water storage*** [together with the more saturated sub-zones] and the areas of ***water recharge*** .
The modeling is completed by shoving the *preferential groundwater flow directions* together with the *sheet water flow directions* [**Fig.10**].

10.0.0 GEOTECHNICS AND FOUNDATION INTEGRATED ANALYSES [Thematic Area No. 7]

«*Earth dam engineering is the art of moulding materials we do not fully understand into shapes we cannot precisely analyze so as to withstand forces we cannot always assess, in such a way that we never-the-less produce safe and economical structures*.»

Henry Bolton SEED

10.1.0 Geotechnics and Foundation Analyses: Methodologies and Data Processing [document No. 37]

10.1.1 Main Activities. Very advanced tools have been devised to develop this last Thematic Area, which is also the arriving point of the entire Research-work. It is important to remark [the note has just been stressed for Geologic studies, in paragraph 7.0.0] that the focus of the activity has been the knowledge of the shallow subsoil layers. In fact, these layers support, in general, the footings of the superstructures and are very important for the interaction problems, also under earthquake loads [Prakash, 1981]. It has to be reminded again that, within the historical town, the buildings [mostly, ancient masonry structures] have, in general, shallow foundations.
The following two research lines have been developed, in this large Thematic Area:
[i] matrix analyses for soil modeling and drawing thematic maps;
[ii] foundation integrated analyses and data processing.

The first research line will be described better in the next sub-paragraphs: "*Geotechnical Calculations and Soil Modeling"* [document No. 38], *"Soil Model Mesh Characterization"* [document No. 39]. In the present sub-paragraph,, it has only to be discussed the innovative "scientific tool" adopted.

Combination of *mathematical classification procedures* and *matrix analysis techniques* has been designed and implemented. This approach appears the most appropriate way of analytically constructing a ***"3-D soil modelling"*** and processing a quantified *"Geotechnical Zoning Map"*.
Within the different stages of the complete process, very interesting has been the contribution given by *Clustering* techniques.
It may be appropriate to mention here that *Cluster Analysis Methods* combined with *Matrix Analysis Techniques* have been applied following specific devoted procedures for "soil modeling", devised by Ciuffi between 1982 and 1986. The said sophisticated procedures, together with the computational algorithms, have been converted into specific copyrighted computer programs. Within a period of about 15 years, the said procedures, further validated in a wide variety of research problems, have been improved progressively.

The second research line within this Thematic Area, is named "Foundation integrated analyses and data processing". A very exceptional effort has been made by the Research-team.
Foundation and geotechnical parameters of each building of the historical town have been searched, collected and studied, one by one.
A parallel search has been developed to analyze the restoration activities implemented after the 1980 earthquake. More than 1.200 structure restoration projects, designed by engineers in 8 years [1982 – 1990], have been examined. Nearly 250 buildings have been selected.
Analyses have been carried out, correlating together, for each single building, the original foundation with the foundation project designed for restoration. All data collected and analyzed have been again processed to prepare an innovative and useful tool: a "Foundation Chart" of the historical town.
For a more through discussion of these issues, see the paper titled *"A FOUNDATION CHART FOR HISTORICAL TOWN RESTORING"*. The paper is printed in the proceedings of the present Conference.

10.1.2 Main Contents. The first part of the written document [No. 37] addresses an overview of the Thematic Area together with a description of the general methodologies and the specific procedures adopted.
Discussed in the second part are the procedures regarding the 3-D geotechnical soil modelling developed. Analyzed are also the results of the proposed soil modeling.
The third part describes methods, data processing and contents [together with the comments] of the graphic results: *"Soil Model Mesh Characterization"* [document No. 39], *"3-D Geotechnical Soil Modeling Map"* [document No. 40] and *"Slope Stability Map"* [document No. 41].

10.2.0 *Geotechnics and Foundation Analyses*: " Calculations for Geotechnical Soil Modeling" [document No. 38]

10.2.1 Main Activities. It is difficult to communicate, in few lines, the complex designed process of *Cluster Analysis Methods*, combined with *Matrix Analysis Techniques*. For this reason, it is opportune to describe only the salient stages, without discussing any single step.
The basic methodology of the designed process can be summarized as follows.

[i] The "*3-D geotechnical soil modelling*" has been designed in a very detailed scale. Each "basic discrete element" of the model has been only 20 cm high. The subsoil of the historical town has been discretized into 54 "main segments", corresponding to 54 Cone Penetration Tests vertical columns. Each column has been then divided into a number of the said "basic discrete elements" [20 cm high]: the number of the said discrete elements has ranged with the depth of each column.

[ii] A complex *"3D soil model mesh"* has been generated, consisting of 3.798 nodes and 5.697 "three-noded elements" :

Table 5. Soil Modeling Geotechnical Characterization

Soil Modeling TOP CLASSES [divided into nine sub-classes]	***Soil Modeling*** ASSOCIATED PARAMETERS [average values] [**Φ**: peak values, including the component related to the *degree of interlocking*]			No.
A1	Gravel+Sand	=	35,76 %	G1
	Silt+Clay	=	64,24 %	
	e	=	0,61 %	
	W/LL	=	0,63	
A2	Ip	=	14.91	
	Ic	=	0,840	
	Φ	=	27°05'	
	C	=	4,33 psi	
	Vp	=	550 m/sec	
B1	Gravel+Sand	=	45,13 %	G2
	Silt+Clay	=	54,87 %	
B2	e	=	0,62 %	
	W/LL	=	0,68	
	Ip	=	13,67	
	Ic	=	0,780	
B3	Φ	=	37°02'	
	C	=	4,36 psi	
	Vp	=	1.200 m/sec	
D1	Gravel+Sand	=	31,00 %	G3
	Silt+Clay	=	69,00 %	
	e	=	0,50 %	
	W/LL	=	0,48	
D2	Ip	=	14,40	
	Ic	=	1,160	
	Φ	=	27°80'	
	C	=	5,99 psi	
	Vp	=	1.100 m/sec	
C1	Gravel+Sand	=	25,96 %	G4
	Silt+Clay	=	74,04 %	
	e	=	0,47 %	
	W/LL	=	0,45	
C2	Ip	=	11,83	
	Ic	=	1,440	
	Φ	=	36°15'	
	C	=	6,41psi	
	Vp	=	2.050 m/sec	

In order to evaluate the most significant parameters for characterizing the said "three-noded elements", *Clustering techniques* have been applied to process the very numerous groups of data generated by the different stages of the investigation program, together with the results of the other Thematic Areas.
It should be noted that the mentioned *Clustering calculations* have consisted of *"non-hierarchical"* methods, developed following iteration processes. Each iteration process has been characterized first, by an *"exploratory phase"* [without having any a priori hypotheses], on a quantitative or binary descriptive table. The second phase, named *"optimization phase"*, has allowed to build the so called *"stable classes"* and to select the most significant solution possible.

[iii] *Basic parameters* have been selected together with a set of *associated parameters*. A complete data base [for each of the 5.697 "three-noded elements"] has been prepared, to be converted into the *"soil model mesh"* designed and then to be merged into specific grids for Clustering calculations. Then, a first group, consisted of two *basic parameters* $\mathbf{q_c}$ [end-bearing (per unit area) in "Cone Penetration Tests"] and $\mathbf{100\ f_s/\ q_c}$ [$\mathbf{f_s}$ is the friction resistance (per unit area) in "Cone Penetration Tests"], has been processed. Subsequently, a second group, consisted of three *basic parameters* [$\mathbf{q_c}$], [$\mathbf{f_s}$] [$\mathbf{100\ f_s/\ q_c}$], has been processed too.
Data processing has generated six main numerical classes [first group] and seven main numerical classes [second group]. These results have been merged all together into a designed *"soil modeling matrix"* .
Further matrix calculations have been performed, generating new four *"top classes"* [divided in nine sub-classes], including also the following selected *associated parameters* :
PSD % [Particle Size Distribution (%)], **Ip** [Plasticity Index], **Ic** [Toughness Index], **W/LL** [Water Content/Liquid Limit], **e** [Void Ratio (%)], **Φ** [Friction Angle], **C** [Cohesion (psi)], **Vp** [Shear Wave Velocity (m/sec)].

[iv] It has been possible to complete the discretization of the subsoil of the historical town. Each "three-noded element" of the *"soil model mesh"* has been characterized, grouped and classified. Very large numbers of calculations have been needed to optimize the results.
The average values of geotechnical parameters characterizing the said four *"top classes"* [together with the nine sub-classes], are summarized in the **Table 5.** As regards Friction Angle, peak values are reported, including also the component related to the *degree of interlocking*.

[v] The last stage has consisted of the *"mathematical inversion"* of the designed *"soil modeling matrix"* , discussed above.
It has been seen that the subsoil of the historical town has been discretized into 54 "main segments" [arranged along **z** axis], corresponding to 54 Cone Penetration Tests vertical columns.
Thus, the *vertical discretization* [along the **z** axis] results have been further processed to be converted into a *horizontal discretization* [on the **x-y** plane].

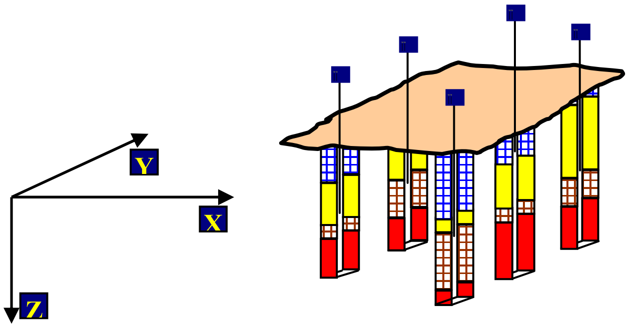


Fig. 11. "Soil Vertical Discretization" Sketch

The objective has been to construct, on the **x-y** plane, a number of *"micro-zones"* being able to include also three-dimensional information generated by the said four *"top classes"* [together with the nine sub-classes], grouping the "three-noded element" of the *"soil model mesh"* [**Fig. 11.**].

10.2.2 <u>Main Contents</u>. The written document [No. 38] is divided into three sections, reporting the different stages of the numerical calculations of the designed *"soil model mesh"*.
The first section contains the *Clustering calculations* corresponding to the first group of two *basic parameters* [$\mathbf{q_c}$] and [$\mathbf{100\ f_s/\ q}$].
Proceeding in the same manner, the second section addresses the *Clustering calculations* corresponding to the second group of three *basic parameters* [$\mathbf{q_c}$], [$\mathbf{100\ f_s/\ q_c}$], . [$\mathbf{f_s}$].
Presented in the third section are the *matrix calculations* related to the *"mathematical inversion"* of the designed *"soil modeling matrix"* .

10.3.0 <u>*Geotechnics and Foundation Analyses*: "Soil Model Mesh Characterization" [document No. 39] and "3-D Geotechnical Soil Modeling Map" [document No. 40]</u>

10.3.1 <u>Main Activities</u>. Based on the discussion presented above, the "Geotechnical Soil Modeling Characterization" has been graphically shown in the document No. 39 and then, further processed, to generate the *"3-D Geotechnical Soil Modeling Map"* [document No. 40].

The results of the calculations, characterizing and classifying each of the 5.697 "three-noded elements" of the *"soil model mesh"* , have been further processed to be normalized. In fact, the peak values, together with localized anomalies, have been recognized and processed, on the basis of a procedure recommended to avoid "excess of data pulverization" and to improve the synthesis.
The final results have been plotted, for each Cone Penetration Test vertical column, discretized as discussed.

In order to obtain a spatial vision of the "Geotechnical Soil Modeling Characterization", the normalized final results have been grouped again into an *inverse matrix* , to be further processed. As just discussed, the objective has been to

construct a *"3-D Geotechnical Soil Modeling Map"*, a graphic document plotted on the **x-y** plane, but being able to include also information generated along the **z** axis.
The *matrix calculations* have generated, at least, four groups, containing three-dimensional information generated along the depth of the subsoil [**z** axis] by the *basic parameters* selected [from the beginning] for the designed *"soil model mesh"*.
The following table summarizes the described results.

Table 6. 3-D Soil Modeling Classes: Relationship between *Vertical* and *Horizontal Discretization*

A [see below]	B [see below]	**qc = Unit End-Bearing in "Cone Penetration Tests"**
3	G1	**qc ≥ 200 Kg/cm²** "Stabilized Average Values" at a medium depth of 4.00 m Within the first 18,00 m., **Average qc = 300 Kg/ cm²**
1	G2	**qc ≥ 150 Kg/cm²** "Stabilized Average Values" at a medium depth of 4.30 m Within the first 18,00 m., **Average qc = 250 Kg/ cm²**
4a	G3	**qc ≥ 100 Kg/cm²** "Stabilized Average Values" at a medium depth of 6.50 m Within the first 18,00 m., **Average qc = 150 Kg/ cm²**
4b	G3	**qc ≥ 100 Kg/cm²** "Stabilized Average Values" at a medium depth of 7.50 m Within the first 18,00 m., **Average qc = 150 Kg/ cm²**
2	G4	**qc ≥ 70 Kg/cm²** "Stabilized Average Values" at a medium depth of 12.00 m Within the first 18,00 m., **Average qc = 50 Kg/ cm²**

A = *"Inverse Matrix"* Data Processing: Soil Modeling Classes of the *Horizontal Discretization* [on the **x-y** plane].
B = Soil Modeling Classes of *Vertical Discretization* [along the **z** axis]. See **Table 5**.

10.3.2 Main Contents. The *"Soil Model Mesh Characterization"* [document No. 39] shows graphically the numerical final results of the "Geotechnical Soil Modeling Characterization".
The said final results, plotted for each Cone Penetration Test vertical column, are shown before and after the normalization process.
The *"3-D Geotechnical Soil Modeling Map"* [document No. 40], shows the different "micro-zones" [corresponding to the Cone Penetration Tests vertical columns] grouped into the described four groups.
The methods followed to prepare the two documents [No. 39 and No. 40], together with the comments, are described in the discussed written report [document No. 37]. The calculations are included in the document No. 38.

10.4.0 *Geotechnics and Foundation Analyses*: Slope Stability Map [document No. 41]

10.4.1 Main Activities. The interactions among the Remote Sensing Data Processing [particularly useful has been the *"Chart of Thermal and Textural Anomalies"*], the Hydrogeologic Studies [an interesting contribution has been given by the *"3-D Groundwater Circulation Model"*] and the Geomorphologic Analyses, have allowed to construct the *"Slope Stability Map"*.
It should be appropriate to state in advance that the slope stability features of the hilly ridge are, generally characterized by a set of phenomena [surface earthflows, "reptatio", etc.], mostly related to the said "Surface Weathering Covers" [sub-paragraph 7.1.0]. It has to be remarked that, in a number of cases, the depth of the said "Surface Weathering Covers" could range around 10.00 m.
Five areas have been recognized and zoned, within the slopes of the hilly ridge.
Two large zones are located on the N.W. slope, where have been identified the discussed areas of ***water storage*** and of ***water recharge***. It is interesting to note that the eastern large zone interacts with the discussed ***"paleo groundwater-flow direction"*** [sub-paragraph 9.2.0].
One smaller zone is located on the N.E part of the historical town, below the Cathedral. It may be interesting to note that the zone is a part of a slope where a landslide occurred, few years ago.
The third large zone is located on the S.E. slope, in accordance with the reconstruction of the *surface drainage pattern*, showing, around the said zones, hydrologic significant elements buried or quite loss.
The last zone, very small, is located on the S.W. slope.

10.4.2 Main Contents. The map [document No. 41] shows the zoning of the said five areas. Also mapped are the *"Linear Features"* [paragraph 7.0.0] together with the ***"paleo groundwater-flow direction"***
The methods followed to prepare the graphic document, together with the comments, are described in the discussed written report [document No. 37].

10.5.0 *Geotechnics and Foundation Analyses*: "Foundation Analyses and Data Processing" [document No. 42] "Foundation Map of the Historical Town" [document No. 43]

10.5.1 Main Activities. It has just been discussed that the second research line within the present Thematic Area, is named "Foundation integrated analyses and Data Processing".

Also emphasized has been the exceptional effort made by the Research-team.

In fact, foundation and geotechnical parameters of each building of the historical town have been searched, collected and studied, one by one.
In addition, a parallel search has been developed to analyze the restoration activities implemented after the 1980 earthquake. More than 1.200 structure restoration projects, designed by engineers in 8 years [1982 – 1990], have been examined. Nearly 250 buildings have been selected.
It may be opportune to repeat that analyses have been carried out, correlating together, for each single building, the original foundation with the foundation project designed for restoration. All data collected and analyzed have been again processed to prepare an innovative and useful tool: a *"Foundation Map of the Historical Town"*.
It is to be remarked that, for a more through discussion of these issues, it is recommended the paper titled *"A FOUNDATION CHART FOR HISTORICAL TOWN RESTORING"*. The paper is printed in the proceedings of the present Conference.

10.5.2 Main Contents. The chart [document No. 43] shows the original foundation scheme of each single building of the historical town, studied, processed and classified together with the foundation project designed for restoration, after the 1980 earthquake.

11.0.0 OVERVIEW ON FINAL DATA PROCESSING [Final Part of the Entire Research-work]

«*Illusion is the most important way of thinking. Man's development is due to his confident belief that he can go who knows where, regardless of what is already known* »
Federico FELLINI

11.1.0 *Overview on Final Data Processing*: Methodologies and Data Processing [document No. 44]

11.1.1 Main Activities. The final part of the entire Research-work summarizes all the stages and the goals achieved and concludes the data processing, proposing suggestion and design indication, for town planners and for future, practice engineering problems.
A general overview of the activities implemented has been made. The methodologies developed and the results obtained within the seven Thematic Areas, have been reviewed. The objective has been to optimize the logic coherence among the different stages and the goals achieved within the main results obtained.
The last data processing activities have been also carried out.
The following two research lines have been developed, in this final part:

[i] correlations among the processed orthophotos;

[ii] construction of the final zoning maps.

The first research line has been addressed to summarize the results obtained and to develop further the "tools" for historical town planning activities and for architectural designs.
Included in this first research line have been the following graphic results [documents No. 45, No. 46, No. 47], obtained.

"1925 – 1955 Urban Evolution Map";

"1925 – 1985 Urban Evolution Map";

"1925 – 1955 - 1985 Digital Terrain Models".

The said documents are not discussed in the present paper, also for giving larger space to the final zoning maps. Only a 3-D result, the *"1925 Digital Terrain Model"*, is shown [**Fig. 4**], together with the corresponding "Ortophoto" [**Fig.5**], just discussed.

The objective of the second research line has been to summarize all the results obtained for constructing the "final zoning instruments". Thus, it has been possible to complete the fixed ***geotechnical integrated system*** a quantified tool, useful for town planners and for further engineering and design activities
Included in this second research line have been the following graphic results [documents No. 48 and No. 49] and the conclusive written report [documents No. 50].
"3-D Geotechnical Zoning Map";
"3-D Foundation Vulnerability Map";
"Geotechnical and Soil-Structure Design Indications".

11.1.2 Main Contents. The report [document No. 44] is divided into three parts.
The first part, addresses a general overview of the final activities.
Described in the second part are the methods followed to prepare the mentioned graphic documents, together with the comments: documents No. 45, No. 46, No. 47.
The third part is devoted to the methods adopted to construct the following final graphic results [documents No. 48 and No. 49] *"3-D Geotechnical Zoning Map"*; *"3-D Foundation Vulnerability Map"*. Also discussed are the results and the comments regarding the said maps.

11.2.0 *Overview on Final Data Processing*: "3-D Geotechnical Zoning Map" [document No. 48]

11.2.1 Main Activities. The Map represents the most advanced effort of synthesis within the entire Research-work.
A devoted *geotechnical matrix* [4 x 4] has been designed for processing the interaction between the "*3-D geotechnical soil modelling*" and a set of Geolithologic and Hydrogeologic features.

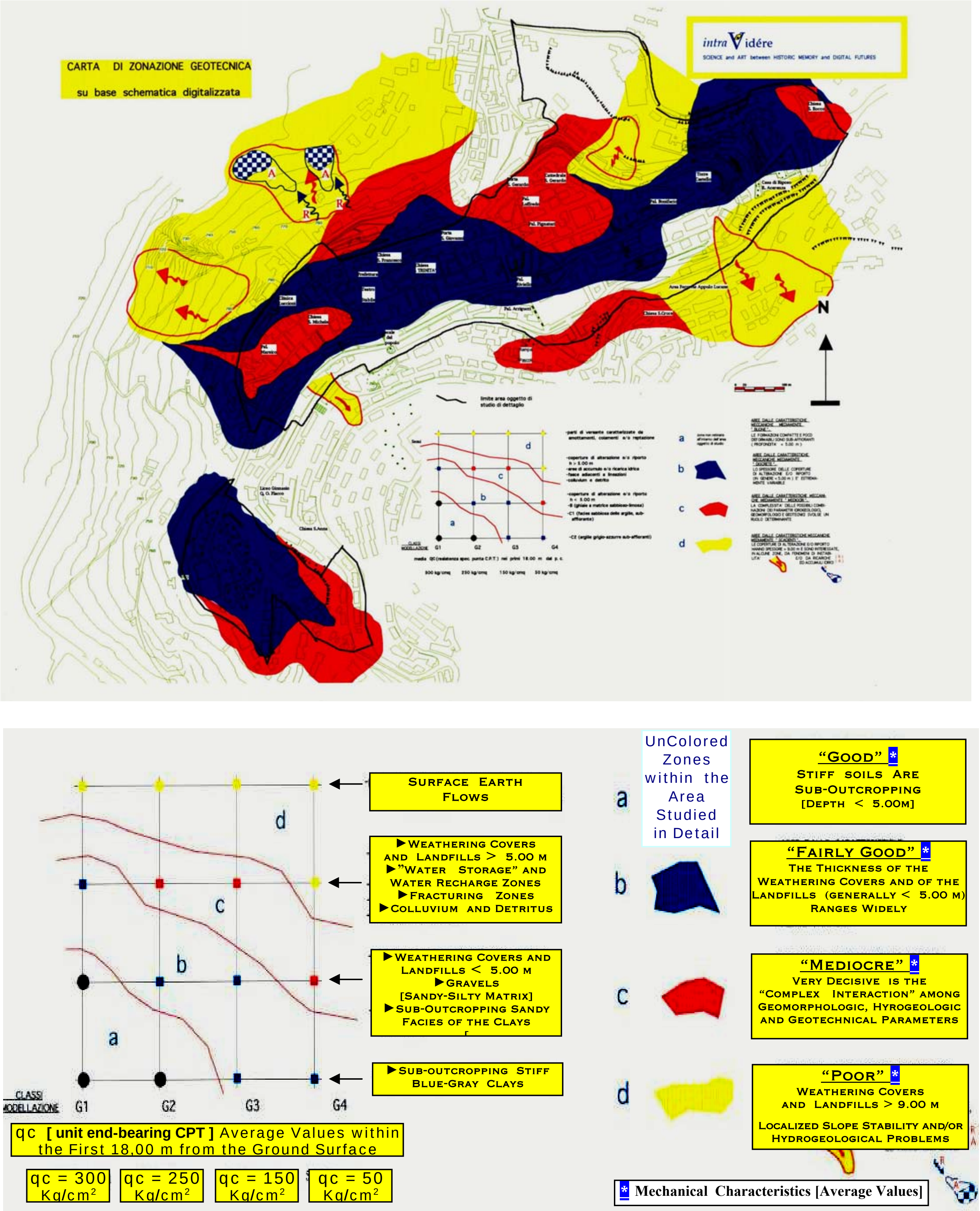


Fig. 12. 3 – D Geotechnical Zoning Map

In particular, the four columns of the said square matrix have corresponded to the numerical four groups generated within the *"3-D Geotechnical Soil Modeling Map"*. It seems opportune to remind that each group has been characterized by an average value of **qc** [end-bearing (per unit area) in "Cone Penetration Tests"] along the first 18.00 m of depth [**z** axis].
The four rows have corresponded to different combinations of quantified results obtained within the Geolithologic and Hydrogeologic studies carried out.
The *geotechnical matrix* processing have generated the following four *definitive zoning classes*, **a, b, c, d**. Each class contains 3-D information and summarizes, simultaneously, Geotechnical, Geolithologic and Hydrogeologic quantified results.
The description of the classes is detailed on the ***"3-D Geotechnical Zoning Map"*** [**Fig. 12**].
It has to be noted that this document includes, at the same time, quantified graphic and 3-D numerical data. It is a very useful tool not only for town planners but also for design engineering future activities. The map could give also important contribution in data processing for predicting soil behaviour, related to anthropic activities.

11.2.2 Main Contents. It can be seen that the map [document No. 48] is divided into two parts.
The first, graphic part shows the detailed *geotechnical zoning* of the hilly ridge, screening the *definitive zoning classes*, **a, b, c, d**. Also mapped are the areas with *slope stability* problems together with the zones of *water storage* and the areas of *water recharge*.
The second, numeric part shows the devoted *geotechnical matrix* [4 x 4] designed for processing the interaction between the *"3-D geotechnical soil modelling"* and a set of Geolithologic and Hydrogeologic features.
The whole of both graphic and numeric parts is organized logically so that the reader can follow and "see" the development sequence [together with the parameters and the numeric values] of the said matrix data processing.

11.3.0 *Overview on Final Data Processing*: 3-D Foundation Vulnerability Map [document No. 49] *"Geotechnical and Soil-Structure Design Indications"* [document No. 50] "

11.3.1 Main Activities and Main Contents. The *"3-D Foundation Vulnerability Map"* represents the final graphic document of the entire Research-work. It summarizes all the information and the results generated within the seven Thematic Areas selected.
This document will not be shown in the present paper because for a correct understanding and appreciation of the different contents of the map, it is necessary to be familiar with the technical aspects and the final results of the research line named *"Foundation integrated analyses and Data Processing"* [see sub-paragraph 10.5.0]. It should be reminded that this research line is discussed in a specific paper titled *"A FOUNDATION CHART FOR HISTORICAL TOWN RESTORING"*. The paper is printed in the proceedings of the present Conference.

It should be noted that the connection between the *"3-D Foundation Vulnerability Map"* and the *"Foundation integrated analyses"* has been very important because the map, developing a further progress of the *"3-D Geotechnical Zoning Map"*, has taken into account also several characteristics and parameters of the existing buildings of the historical town.

The following, last table summarizes the most important aspects of the new matrix designed.
The four *definitive zoning classes*, **a, b, c, d** [**Fig. 12**] have been divided into eight sub-classes to be further processed together with the results of the *"Foundation integrated analyses and Data Processing"*, and the outputs of the last document [No. 50] named *"Geotechnical and Soil-Structure Design Indications"*.

Table 7. Foundation Vulnerability Matrix

Geo-tech-nical Zoning Classes	**Geo-tech-nical Zoning Sub-Classes**	**Mechanical Charac-teristics** [For he Quantified Numerical Parameters See the *"3-D Geotechnical Zoning Map"*]	**Average Slope**	**Contacts Among Different Forma-tions** and/or **Landfills > 2.00 m**	**Existing Buildings** ***"Foundation integrated analyses and Data Processing"***	**Key Words for Restoration Works or New Constructions**
a	**a1**	Good	< **15%**	No	F1	**K1.1**
	a2	Good	> **15%**	Yes		**K1.2**
b	**b1**	Fairly Good	< **15%**	No	F2	**K2.1**
	b2	Fairly Good	> **15%**	Yes		**K2.2**
c	**c1**	Mediocre	< **15%**	No	F3	**K3.1**
	c2	Mediocre	> **15%**	Yes		**K3.2**
d		Poor	< **15%**	No	F4	**K4.1**
		Poor	> **15%**	Yes		**K4.2**

The four classes generated within the *"Foundation integrated analyses and Data Processing"*, **F1**, **F2**. **F3**. **F4** include several sets of parameters of the discussed exceptional effort, made by the Research-team.

Thus, the said four classes summarize the results of he different stages data processing, carried out, correlating together [for each single building of the historical town] the original foundation with the foundation project designed for restoration activities implemented after the 1980 earthquake.
It may opportune to remark again that more than 1.200 structure restoration projects, designed by engineers in 8 years [1982 – 1990], have been examined. Nearly 250 buildings have been selected.

The four classes **K1**, **K2**. **K3**. **K4** [together with their sub-classes] selected within the last document, *"Geotechnical and Soil-Structure Design Indications"*, have been the ***"core"*** of the *decision process of the historical town restoring. and managing.*
Within the said document No. 50, the eight sub-classes of the *"3-D Geotechnical Zoning Map"* have been analyzed, one by one, in order to produce suggestions and exact indications, related to potential future engineering activities or addressing works to be implemented for increasing the safety margin, within a number of "problematic areas".
For each sub-class, a specific *"card planning"* has been prepared, for summarizing the results divided into two sections: "<u>characteristics and problems</u>" and "<u>corresponding indications</u>".

It has to be emphasized that both the final documents No 49 [*"3-D Foundation Vulnerability Map"*] and No 50 [*"Geotechnical and Soil-Structure Design Indications"*] represent a complement set and are to be read and used together, for practice activities.

12.0.0 CLOSING OVERVIEW

*«…And He who sites on the throne said, " **Behold, I am making new all things"** ….* »

<u>"Apocalypse" of St. JOHN</u>

12.1.0 <u>*Closing Overview*: First Field Validation of the Research-Work Implemented</u>

The subsoil Research-work has been finished, as mentioned, in the March 1994. Therefore, the contribution of *geotechnics in the decision process of the historical town restoring* has continued. In fact, on the basis of the final results of the subsoil Research-work, the town planners have been able to conclude, subsequently, their activities. Then, the long administrative *decision-making process* has been developed, by the City Council.
In the July 1997, a public presentation of the complete *decision process* has been made to the whole town. In that occasion, it has been possible to communicate the first field validation of the subsoil Research-work implemented. In fact, a few weeks before the official presentation, a gravity retaining wall [around 4.00 m high and 6.00 m long] has collapsed [on the N.E. slope of the historical town], damaging, luckily only a car, without people. It is interesting to emphasize that the retaining wall has collapsed exactly within a zone classified ***"poor"*** [the term is a <u>"quality"</u> indication of <u>quantified</u> and numerical parameters, as seen in **Fig. 3**] in the ***"3-D Geotechnical Zoning Map"***, in which such problems have been predicted. The last figure shows the location of the collapse, around a boundary line between two very different soils. This is further confirming how definite the prediction has been.

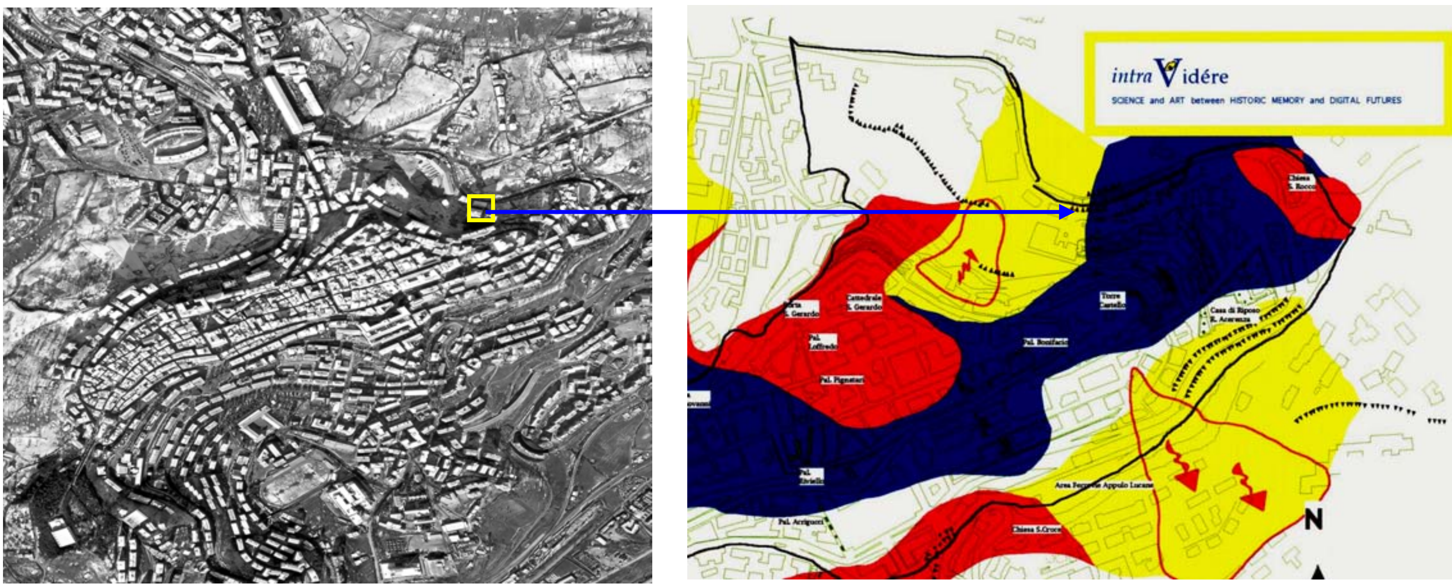


Fig. 13. *Location of the COLLAPSE of a Retaining Wall, Occurred in 1997. [The small area, shown on the 1980 Aerial Photo, has been correlated with the corresponding zone of the "3-D Geotechnical Zoning Map"]*

12.2.0 *Closing Overview*: Walking Towards the Future

What are the most interesting reflections suggested by the present *case-history*? What is the best way for allowing the reader to conclude his trip through this paper, appreciating its several challenges? Many pages have been just required, so, only four flashes for closing.

▲ The prefixed main objectives have been achieved.
The city of Potenza has been provided with an innovative ***geotechnical integrated system***, a quantified tool, very useful for the following specific goals, within its historical town:

- ▲ Town Planning and Managing;
- ▲ Seismic Prevention Designing Activities;
- ▲ Civil Engineering Design Activities;
- ▲ Architectural and Restoring Designing Activities;
- ▲ Data Processing for Predicting soil behavior related to several anthropic activities.

▲ The Research-work implemented, in addition to the objectives achieved, represents an original guide. In fact, the basic approach, together with the methods adopted and the procedures developed can be applied to other such situations, designing the best set, case by case.
For this purpose, it should be underlined that the said methods and procedures can be applied not necessary all together, but also separately [for example, in a specific research, only two methods could be enough], in a "modular" way.
Finally, a number of the said methods and procedures could be positively exchanged and, if necessary, reviewed and taught. Encouraged is a co-operation with public and private institutions, in order to organize a permanent plan of technical training. Very recommended is the organization of devoted "short courses" for training young people to have an "open mind", more and more needed, not only in scientific activities.

▲ It is confirmed the well known basic role of the following key-words: Creativity, Innovation, Logic, Interdisciplinary approach. Therefore, it should be noted that the present Research-work adds the specific "value" of the ***"Unity".*** Each key-word, even essential, needs strong synergies, to multiply its value and optimize its practice contribution, within a specific research.
Thus, ***"Unity"*** becomes the new frontier also for the "act of Researching", in any field.
It has just been mentioned that, thanks to ***"Unity"*** sophisticated technologies and advanced scientific methods come into communication with ancient documents and episodes in the "lives" of a historical town.
Thanks to ***"Unity"*** different persons may have the pleasure to plan *together*, to create *together*, to innovate *together*, to design and to check *together*, unifying their apparently disjointed analyses, questioning and examining their own specificities, without ever taking anything for granted. When professor Shamsher Prakash remarks [1981], ironically, *«Fundamentally speaking, a definition for dynamic bearing capacity has not yet evolved! »*, he gives us a profound lesson of Knowledge and opens the doors for the final flash of this paper: the *permanent creative tension.*

▲ The *enthusiastic, permanent creative tension* is the last "challenge" that is proposed to the reader. Therefore, the *permanent spirit of innovation* is also the occasion to realize the message of the Spirit of the "Apocalypse" «…***" Behold, I am making new all things"*** … ».
As it has been seen, a large number of advanced methods and techniques have been mentioned and discussed. Because they are referred to the period in which the Research-work has been implemented, in a number of cases, they could be outdated, so as described in the paper. In such cases, they have been progressively updated, or also deeply innovated, *creating new* solutions, on the basis of the "enthusiastic, daily creative tension".
This confirms that the Research-work, summarized in this paper, is also a bridge between the *past* and the *future*. In fact, the final documents produced and discussed, in the previous paragraphs 10.0.0 and 11.0.0, represent the most advanced effort of synthesis within the entire Research-work. But they contain also several, important knowledge-elements for designing the *possible futures*.
All this is in perfect accordance with the choice of the Organizing Committee to plan the present Conference at NEW YORK. It is easy to read in this choice also a symbolic meaning: the strong will to ***continue creating, day by day***.
In this context, the "Fifth International Conference on Case Histories in Geotechnical Engineering" may sublimate its high scientific activities with a profound act of Love, inaugurating a new style for *walking towards the Future*.

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