THE FIUMARELLA BRIDGE: CONCRETE CHARACTERIZATION AND DETERIORATION ASSESSMENT BY NON DESTRUCTIVE TESTINGS

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Abstract - In this paper the results concerning a non destructive investigation conduced in situ on a concrete bridge built approximately on thirties in province of Reggio Calabria are reported. The study of "ancient" concrete is interesting because provides information about materials and technologies available at the time of production and the knowledge of the main physical properties of concrete and its state of conservation. The Laser Scanner technology is applied for measuring the geometrical property of structural elements of concrete bridge and the Georadar technique is applied instead to the determination of the intern morphology, to the lack of homogeneity research and defectiveness and to the determination of the location of the steel reinforcements. The Laser Scanner technology (LST) allows to reproduce 3D physical models through single succeeding scanning. In this paper the LST is utilized for the geometric survey of the concrete bridge and the solid model created by the laser scanner is acquired automatically from a finite element programme. Moreover the research is oriented to understand the composition of the mixture used in the casting of concrete bridge and the actual state of its deterioration and strength. In fact, in addition to in-situ observation and measurement of mechanical strength of concrete, in this work, the help of Hearth Science analytic techniques is considered. These are employed to: (i) distinguish the typologies and the composition of inerts and binder fraction and their percentage used in the concrete (ii) obtain the porosimetry of concrete in order to determine total pore volume area (MIP: Mercury Intrusion Porosimetry), (iii) estimate the level of chemical deterioration with the determination of soluble salts (Ion Chromatography) presents inside the material.

Keywords: Laser Scanner, Georadar, concrete, steel reinforcement, Hearth Science techniques, Bridge.

1 Introduction

Characteristics and properties of concrete depend on raw materials utilised, because they are important in conferring resistance and protection to constructions.
In this work different non destructive methodologies were used to investigate the Fiumarella bridge concrete built approximately on thirties in province of Reggio Calabria. This bridge reveal an evident state of deterioration (Figures 1 and 2), in particular in the side in front of the sea, with subsequent detachment of concrete and exposition to the weather agent of the steel reinforcements [1] .
During the first time of the project, laser scanner measurements were carried out to determine the geometrical property of structural elements of the concrete bridge; subsequently Georadar technique was applied to establish the intern morphology of concrete.

Fig.1 - The Fiumarella bridge

The analysis were followed by non-destructive investigation (penetrometers, sclerometers and ultrasonic methods) with the aim to determine the mechanical resistance, to give an indication of the original quality of the concrete and its subsequent deterioration. In the last phase of work, three different specimens of concrete were take from the bridge and investigate with different Hearth Science analytic techniques (Figure 2).

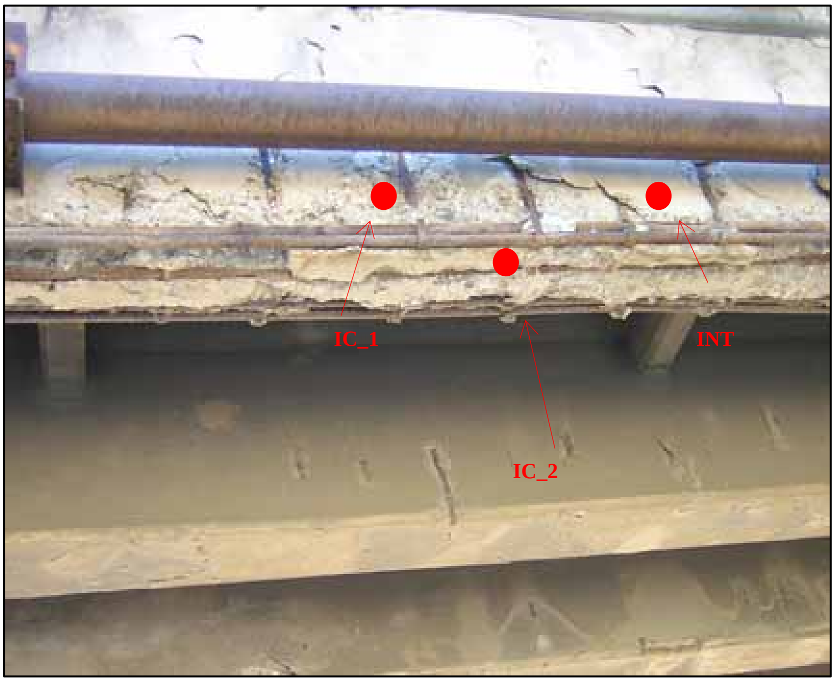


Fig.2 - Specimens of concrete, take from the Fiumarella bridge

2 Laser scanner technologies

Geometrical property, of structural elements of concrete bridge, are obtained with LST that allow us to reproduce 3D physical models, through single subsequent scanning and to create automatically the solid model from a finite element programme. [1, 2, 8]

LST is based on a system that consent to create highly accurate three-dimensional images of objects, for use in standard computer-aided design software packages. This system offer a wealth of information about a structure surface in the form of a dense set of 3D point measurements using a laptop computer, laser scanner, and tripod. Images are developed from a pulsing laser beam capable of capturing an high number of data points per second up to 150 meters away. As an object is being scanned, each 3D measurement appears immediately as a graphical 3D point image on the laptop screen. This cloud of points is a dimensionally accurate representation of the existing object. Further enhancements, such as shrink-wrapping using Cyra's Cyclone software, can be made depending on the laser scanning software capabilities. Besides obtaining 3D images from laser scanning and the provided software, it is possible to export point cloud data to CAD applications. However, the large point cloud image and triangulated mesh files can sometimes overwhelm a CAD application. The size of a file depends on the size of the object that will be scanned. In order to successfully complete the transfer, some of the points will need to be deleted [3].

3 Georadar technologies

Ground-penetrating radar (GPR or Georadar) is a geophysical method that uses radar pulses to image the subsurface, it is also employed to execute controls on the reinforced concrete structures. This technique is being one of the most diffuse among non-destructive methodologies of investigation, in the field of structural engineering. Based on non-destructive and non-invasive techniques, it uses electromagnetic radiation in the microwave band of the radio spectrum, and detects the reflected signals from subsurface structures.
This technology is based on the same principle as conventional radar systems, but in Civil Engineering it is used with a few important differences. Infact, in this case, the GPR [4, 5] works on distances of few meters and not on many kilometres as in conventional radars [1, 6].

4 Hearth Science analytic techniques

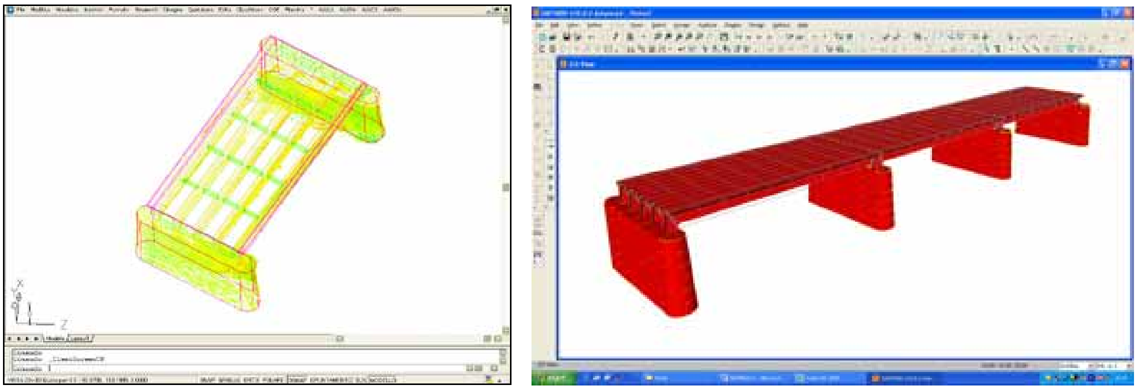
The characterisation of concrete composition is obtained with the help of Hearth Science analytic techniques.
The first phase is characterised by petrographic analysis of thin concrete sections, with a common polarising microscope; follows X-ray diffraction analysis based on a crystallographic technique, in which the pattern produced by the diffraction of X-rays through the analysed material is recorded and then analyzed to reveal the nature of specimen. The use of X-ray powder diffraction is frequent in materials science because specimen preparation is relatively easy, and the test conduction is rapid and non-destructive. The pattern of powder diffraction peaks can be used to quickly identify materials; changes in largeness peak or position can be used to determine crystal size, purity, and texture.
Successively Ion Chromatography technique is carried out on the plaster specimen. This technique consist in the separation and quantification of anions (i.e. fluorides, chlorides, nitrites, nitrates, phosphates, sulphate, oxalates) and cations (i.e. lithium, calcium, sodium, potassium, ammonium, magnesium) present inside the analyzed specimens; the separation of the mixture components occur in a solution by selective absorption; once the components have been separated they are measured by a conductivity detector.
The calcimetry analysis is employed to estimates the CaCO3 percentage present inside a specimen of plaster. This technique is based on a volumetric method for the evaluation of unsolved material present in a solution of HCl. The carbonates present in the specimen are converted into CO2 by adding hydrochloric acid to the specimen. As a result of the pressure of the CO2 released, the water in a burette that is de-aerated, rises. The difference in level measured is an indication for the released quantity of CO2, from which the carbonate content can be calculated. The carbonate content is expressed as an equivalent calcium carbonate content.
Another technique used is the porosimetry. This consents to determine various quantifiable aspects of a nature porous material, such as pore diameter, total pore volume, surface area, and bulk and absolute densities. The technique involves the intrusion of a non-wetting liquid (often mercury) at high pressure into a material through the use of a porosimeter. The pore size can be determined based on the external pressure needed to force the liquid into a pore against the opposing force of the liquid's surface tension.
Last technique used is the Thermogravimetric Analysis (or TGA). This is a type of testing that is performed on specimens to determine changes in weight in relation to change in temperature. Such analysis relies on a high degree of precision in three measurements: weight, temperature, and temperature change. A derivative weight loss curve can be used to tell the point at which weight loss is most apparent. A simultaneous DSC-TGA device that can be used to characterize any material exhibiting a weight change or a phase change between ambient and 1000 oC.(i.e.); the mass of a substance and the difference in energy inputs into a substance and a reference material are both measured simultaneously as a function of temperature while the substance and reference material are subjected to a controlled temperature program. The DSC-TGA plot showing the melting peak and the weight loss occurring at the elevate temperatures.

5 Case study: The Fiumarella bridge, results and discussion

In this section the more important results of non destructive investigation conduced in situ on a concrete bridge built approximately on thirties in province of Reggio Calabria are shortly reported.

5.1 The laser scanner results

The application of laser scanner technology consented to obtain detailed information about the geometric property of the bridge without the uses of direct measurement. The point cloud obtained by laser scanner were exported to CAD applications where the structural model of bridge was generated and subsequently acquired automatically from structural software. Figure 3 shows the Laser Scanner application results and the 3D FE model (of structural element) of bridge generate by Sap 2000 code [8].



a) b)

Fig. 3 – Laser Scanner Application Results: a) point cloud exported to CAD applications (file dxf), b) 3D FE model of Bridge imported in Sap 2000 code

5.2 The Georadar Application Results

With the use of the technique described above, we obtained detailed information about positioning and number of longitudinal steel bars and stirrups enclose in structural elements of the considered bridge. Moreover concrete covers and step of stirrups were obtained for all structural elements of bridge. The results of the conducted investigations on a longitudinal beam of bridge is reported in Figure 4 where the geometric property of the beams, their length, the number of the included stirrups, the number of longitudinal steel bars and the concrete covers are showed.

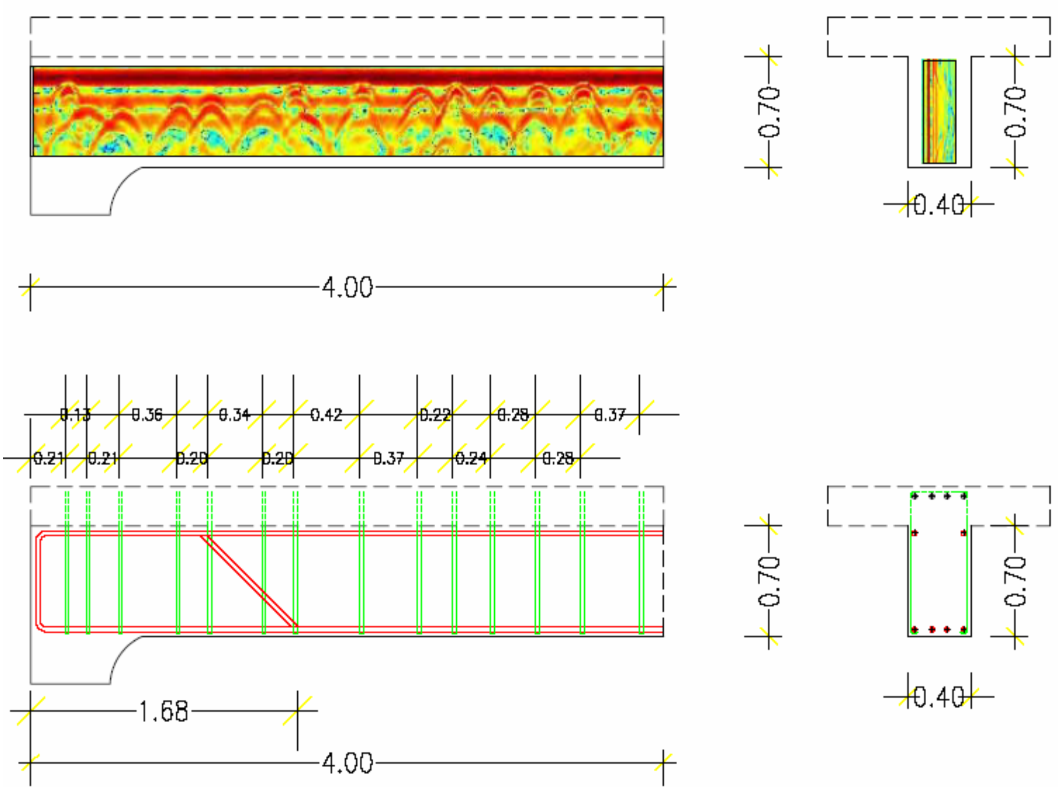


Fig. 4 – Georadar Application Results

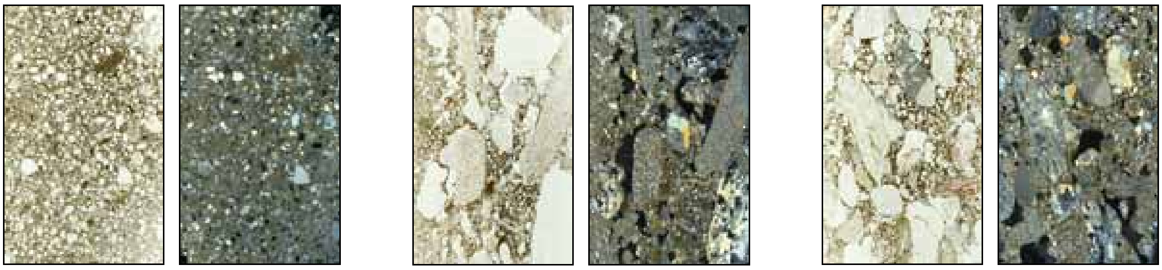
5.3 The Hearth Science results

The first phase is characterised by petrographic study of thin concrete sections (see Fig.5), supported by an image analysis method [7] with the purpose to establish the mineralogical and petrographic composition, and the fraction of binder, aggregate and porosity.

Concrete specimens are constitute by a conglomeratic aggregate (maximum size 1.5 cm), not oriented with inhomogeneous distribution. The aggregate is poorly classed and it's show high density (50% of grains); it's composed both of mono-crystals (above all quartz and k-feldspar) than fragments of rocks (granitoides, metamorphic, quartz-sandstone and some calcareous fragment). The cement is micritic and locally microcrystalline (for the deterioration). Porosity is irregular with maximum size of 4mm principally near of biggest grains; the most represented class of pores is included between 0.01 and 0.1 micron and 100 micron (see Fig.-6)
Plaster specimen is constitute by a medium arenaceous aggregate (maximum size 3 mm), not oriented, with homogeneous distribution. The aggregate is well classed and it has medium concentration of grains (30%); it's mainly composed by mono-crystals (quartz, orthoclase, microcline and plagioclase) and some fragments of rocks (quartz-sandstone). The cement is micritic. The percentage of porosity is low (6% of pores) with maximum size of 0.6 mm and sub-rounded form. The most represented class of pores is included between 1 and 10 micron (see Fig. 7)
Results of image analysis, carried out on the three examined specimens, are reported in Table 1.

Table 1 - Results of image analysis

Specimen	Porosity [%]	Cement [%]	Aggregate [%]
INT 1	5.21%	56.35%	38.44%
IC 1	9.754%	20.53%	69.71%
IC 2	12.97%	24.21%	62.82%



INT 1 **IC 1** **IC 2**

Fig. 5 – Thin sections of examined specimens in natural light (left) and in crossed polarised light (right)

Mercury porosimetry technique has been used to investigate material porosity. This technique is characterized by applying various levels of pressure to a specimen immersed in mercury. The pressure required to intrude mercury into the specimen's pores is inversely proportional to the size of the pores.

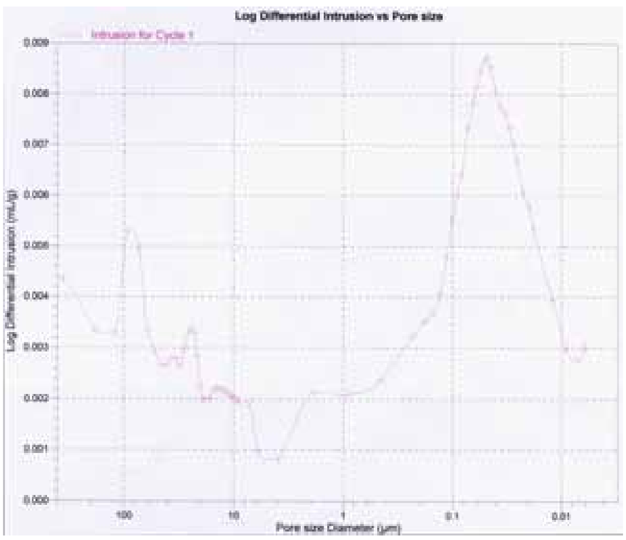


Fig. 6 – Pores size distribution of IC specimens

The petrographic study is supported by X-ray diffraction techniques for individuation of mineralogical phases present in the specimens and eventually the presence of typically minerals of deterioration.

The diffraction spectrum of INT_1 (see Fig.8) specimen are reported following. The mineral present (in abundance order) are: quartz, calcite, plagioclase, K-feldspar, dolomite, ettringite, portlandite. Moreover, traces of thaumasite and sulphide are recorded.

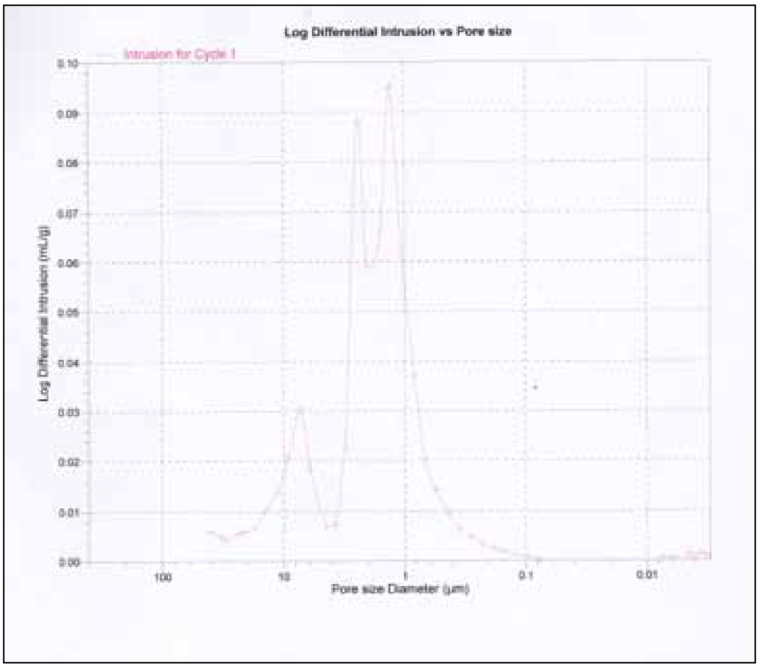


Fig. 7 – Pores size distribution of INT_1 specimen

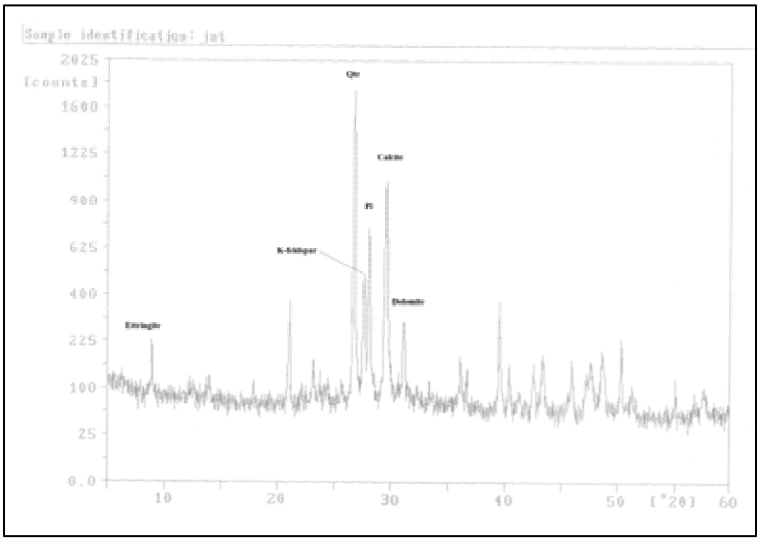


Fig. 8 – Diffraction spectrum of INT_1 specimen

Ion Chromatography technique is carried out on the INT_1 specimen with the aim to estimate the chemical deterioration. The presence of soluble salts inside the material influence the degradation of the bridge.
This results are reported into two graphics for anions (fluorides, chlorides, nitrates, phosphates, sulphate) and for cations (calcium, sodium, potassium, ammonium, magnesium) respectivey (see Fig. 9).
The components present are showed in the table 2. The anomalous content of sodium, chloride and sulphate are principally related to the closeness of sea. Instead the high content of calcium are typical of the concrete.
After, the INT_1 specimen is submit at calcimetry analysis for estimate the percentage of $CaCO_3$. The content of $CaCO_3$ is about the 30,1% due to the concrete carbonation.
The graphics of thermogravimetric analysis is shows in figures 10 and 11 where it is possible to see the characteristic weight peaks and downs of each minerals.
In the first graphic (Fig. 10) the TG curve shows five important points: the first corresponding to loss in weight of gypsum and water of capillarity, the second corresponde to presence of ettringite, the third coincide whit the phase transition from quartz-α to quartz-β, the fourth wit the decomposition of α-C_2SH and the last coincide whit the calcite

and totally decarbonation. In the second graphic (Fig. 11) the TG curve shows three mainly points corresponding: to loss in weight of gypsum, at phase the transition of quartz-α to quartz- β and to loss in weight for decarbonation and calcite.

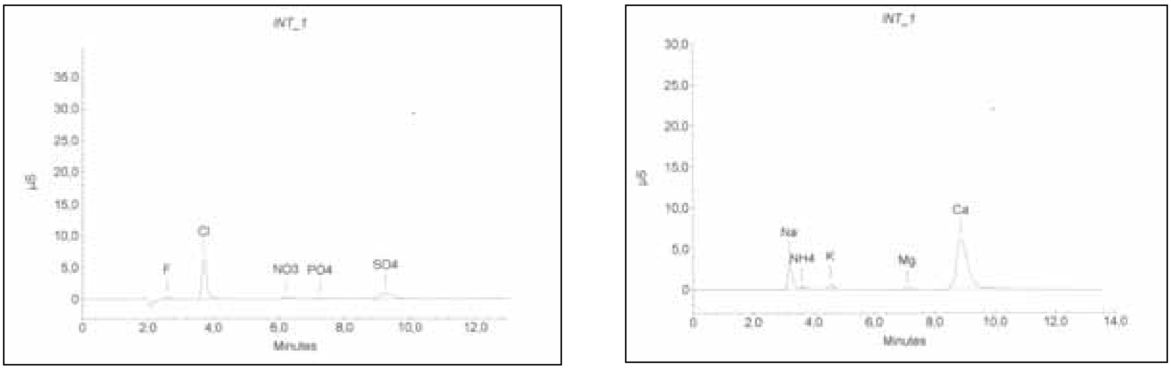


Fig. 9 – Concentration of soluble salts in the INT_1 specimen

Tab.2 – Amount of soluble salts in the INT_1

Component	Amount (ppm)
Na	2933,58
NH4	50,06
K	720,88
Mg	50,06
Ca	11133,57
F	110,13
Cl	4635,65
NO_3	550,67
PO_4	680,83
SO_4	3023,68

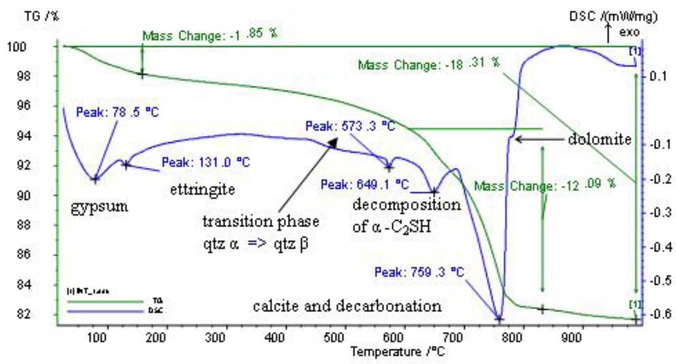


Fig. 10 – Thermogravimetric analysis of INT_1 specimen

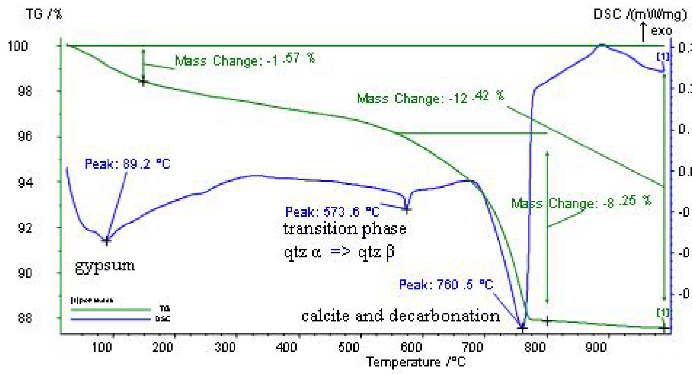


Fig. 11 – Thermogravimetric analysis of IC_1 specimen

6 Conclusion

A non destructive investigation conduced in situ on a concrete bridge were reported. The Laser Scanner technology, the Georadar technique and Hearth Science analytic techniques were applied and commented upon. The LST is a very advanced non-destructive instrument and provide structural information with elevated resolution. It has consented a very detailed 3D acquisition of the bridge whit the possibility to elaborate the model with many level of detail. The system has allowed to reproduce, through single succeeding scanning, 3D physical models of the bridge, formed by million points, each of them identified by real x, y, z coordinates, and subsequently its automatically acquisition by a structural software. However, the large point cloud image and triangulated mesh files can sometimes overwhelm the CAD application.

The Radar methodologies and the results achieved whit its application consent to affirmed that the uses of radar methodologies to map utilities, and for applications to civil structures with special regard to the determination of the intern morphology, to the lack of homogeneity research and defectiveness and to the determination of the location of the steel reinforcements seems to be able to provide good planimetric and three-dimensional restitution.

The deterioration of concrete bridge are correlate with the following phenomena: sulphation (presence of ettringite, gypsum and traces of thaumasite above all in the plaster specimen, that it isn't enough deep to cover the reinforcement steel), carbonation (presence of $CaCO_3$ in the specimens) and chloride attack (frequently related to sea environment). Besides, the macro-porosity, present inside the specimens, is due to poorly classed inerts used for the concrete, this may support the detachment of plaster. $CaCO_3$ help this phenomenon, infact the reaction with CO_2 forms $Ca(HCO_3)_2$ soluble in H_2O and this produce the taking away of the concrete. The carbonation, also, promote corrosives processes of the steel reinforcement and favour the deposition of oxides with consequent diminution of resistant section. The increase of steel reinforcement volume determine the crack of surrounding concrete and the infiltration of chlorides that allow the detachment between aggregates and cement.

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