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Prof. Fernando Sansò

DOCTORAL PROGRAM IN GEOMATICS AND INFRASTRUCTURES

The Doctorate of Geomatics and Infrastructures continues the tradition of the previous Doctorate in Geodesy and Geomatics, dating back to the first cycle of doctorates in Italy of the years 1983-86. Thus, according to the vision of the Doctorate School of Politecnico di Milano, we are working now within an interdisciplinary environment.
The original field of geomatics, which in any way was already quite extended, has become even larger, enriched by disciplines that beyond defining the shape of the "Surface of the Earth" look at its use too as support of human activities, in particular infrastructures (road, railways, airports, etc.) and even at its stability, due to the interaction with first layers of the earth structure (applied geology). So, viewing the field of activity of the doctorate in terms of heights, we could say that we produce research on topics like: satellite geodesy (maintenance of global reference systems, orbit determination, global gravity field recovery), satellite earth observation (satellite positioning – GNSS remote sensing, high resolution imaging), airborne observation (aerogravimetry, digital photogrammetry and image analysis, LIDAR and SAR surveying), ground surveying and mapping (traditional and modern surveying, topographic data bases, geographic information systems), cultural heritage surveying (determining and archiving the shape of architectural and artistic works), structural control (surveying and controlling the geometry of structures and infrastructures at submillimiter level), navigation (inertial and satellite assisted navigation), traffic modelling and control (roads safety measures), designing, building and repairing infrastructures (technology and security on construction sites), monitoring the slope instability (identification, characterization and reconstruction of slopes dynamic), detecting geodynamical signals (crust deformation monitoring, subsidence, gravity field monitoring).
The doctorate is articulated into 3 branches: geodesy and geomatics, surveying and geomatics, infrastructures. It offers to students high level courses in the different branches for 60 credits, and supports their participation in international research activities. After two mandatory courses of overview of geomatics and data processing, students can attend one of the following programs:

Geodesy-Geomatics branch
- Data processing 2
- Geomathematics
- Image analysis and digital photogrammetry
- GPS
- Geographical Information Systems

Surveying-Geomatics branch
- Local surveying
- GIS: applications
- Remote sensing
- Applied photogrammetry
- Architectural surveying

Infrastructure branch
- 15 credits chosen from other branches
- National Summer School on Infrastructures

Furthermore there are elective courses to be chosen among: Satellite geodesy, Gravity field modelling and geoid estimation, DTM generation, Advanced spatial representation, Navigation and kinematic surveying, Geomatics and planning, Road experimental laboratory (advanced course).

Ultimately it steers students in the production of a doctoral thesis. The quality of the work of the doctorate, from courses to the theses, is checked annually by a committee of national and international referees.

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DEVELOPMENT OF A METHOD FOR DEFORMATION ANALYSIS BY TERRESTRIAL LASER SCANNING

Ivan Mario Alba

The acquisition techniques, the analysis and elaboration of data acquired by *terrestrial laser scanning* (TLS) are diffusely used in different fields: generation of 3D models, reverse engineering, documentation of the state of health of anthropogenic buildings or natural sites.
The ability to detect the object surface by a dense and accurately point cloud gave rise to interest for the application of this instrument in deformation analysis that an object can undergo over time.
This operation is easy and has a direct implementation where the measurement precision of TLS is significantly lower the amount of deformations. However, there are many fields in which the deformations are smaller than the precision and it cannot be measured with reasonable certainty. One of these fields are big civil structures (dams, bridges, towers, etc...) where they are currently used in the classical methods for static monitoring that are based on the accurate determination of a limited number of points.
The use of TLS permits us to explore all extension of the analyzed surface and gives more information about the state of health and conservation of the structure.
A second important area where TLS techniques are becoming of primary importance is that of geological monitoring.
In this case the use of TLS techniques is more interesting than the civil field because the natural structures can cause inhomogeneous and irregular surfaces.
In this thesis a method for deformation analysis based on the use of terrestrial laser scanning techniques has been developed and tested.
This methodology has been designed with a level of flexibility that can be used for both civil and natural structures (regular and irregular surfaces). Rockfaces provide a comprehensive example of these features: their complex morphology and the presence of multiple factors that change their shape (growth, detachment and deformation) have been demonstrated as an ideal case to validate the proposed methodology.
Before proceeding to field trials, different tests have been carried out to analyze the metrological characteristics of the TLS instrumentation.
In particular, some major aspects for the monitoring operations have been analyzed, like the accuracy and repeatability of measurements. To increase the precision of measurement on the distance two different methods which exploit samples of repeated measures in time ("multiscans") or spatially (filter "Octree"), have been analysed...
The ratio between scan time and accuracy is almost the same for both methods, but the maximum efficiency is obtained by combining them together.
Subsequently, the measurement accuracy on some kind of retro-reflective targets commonly used for the operations in scan geo-referencing has been analysed.
The results of some experimental tests showed a systematic error on the distance measure that causes an error for the center coordinates of a target.
To reduce this effect two different methods have been tested: a first recalculation of the position of the target center with different algorithms than those implemented in commercial software, while a the second try has been carried out to model the measurement error as a function of the distance and the incidence angle between laser beam and target.
Both methods have helped to reduce errors and the accuracy of georeferencing has been improved by about 40% for the first method and 15% for the second.
Despite improvements in the georeferencing based on retro-reflective, target are still affected by errors because of it is not possible to completely remove the systematic effects.
These can be minimized through the use of some simple procedures, such acquired data from the same stand point and the use of a distribution of target that provides a stable georeferencing.
For this reasons, different strategies for georeferencing the scans have been tested during the monitoring tests. In the thesis different methodologies have been compared among them, including one that provided the best results and uses a mixed technique.
Thanks to the positioning of the instrument on a pillar the translations of the intrinsic reference system have been constrained while the rotations have been calculated by using an algorithm of surface matching.
Although this methodology provides results far superior than others, it can not be considered of universal validity. The choice of the most suitable method for georeferencing depends on the boundary conditions of each case.
Besides the problem of scan georeferencing, another aspect related to the presence of vegetation on cliffs has been addressed because the its presence does not correctly permit the acquisition of the rockface surface. Initially, common spatial filters present in literature for the treatment of ALS (Airborn Laser Scanning) data have been tested. Before applying the algorithms the data have been adjusted to be used for rockfaces. Unfortunately, none of these techniques has allowed us to solve the problem in a comprehensive way. For this reason, the use of *Near Infrared Red (NIR)* images has been tested for the automatic recognition of vegetation.
After building a low cost NIR camera from a standard digital reflex, different algorithms based on the most common vegetation indices used in Remote Sensing have been tested. The results were very encouraging, from images acquired in the laboratory sample field some selection masks to discriminate the vegetation have been created using algorithms designed specifically. Through these masks the vegetation can be easily removed from the point clouds.
Finally, an algorithm for the analysis of deformation, by which the deformations and the detachments can be automatically extracted and interpreted has been developed.
Before proceeding to the calculation of deformation it is necessary to eliminate all macroscopic variations of form on the surface. This task is carried out with the enhancements of any vegetation and postings of the rock blocks recorded by the difference of the DEM acquired in two epochs (ΔDEM). For this reason all the detachments have been identified according to two thresholds related to the depth and width.. The algorithm provides in output a map of the collapses and for each of them calculates its volume and location. This algorithm has been applied not only on the rockface but it has been examined on a pair of synthetically generated DEMs.
The results have been very satisfactory in both cases: all the collapses have been identified and the estimated total volume of the collapses has been very close to the simulated one.
Once purged of any detachments or increasing, ΔDEM is analyzed by a second algorithm which allows us to measure the deformation through a window media.
The algorithm provides two maps: the first one shows the deformation while the second one provides guidance regarding the statistical significance of deformation. Again, the performance of the model generated synthetically made it possible to validate the algorithm. Indeed, this has been able to measure the deformation with a precision of 1/5σ. Differently, as expected, in the real case a significant deformations of the rockface has not been identified.
Like most of those present in the literature, the algorithm has been based on the principle not to calculate the movements of individual points recorded, but it calculates them over a portion range. This technique allows us to significantly improve the precision of deformation measurement as a function of the number of points used to sample but consequently increase the correlation between the data that leads to an overestimate of the accuracy.
For this reason a model for empirical estimation of the covariance between the data has been proposed.

INNOVATIVE METHODOLOGY TO ASSESS THE EFFECTS OF GEOCOMPOSITE REINFORCEMENT ON ASPHALT CONCRETE PAVEMENTS

Matteo Bacchi

In most European countries, the premature pavement deterioration may be due to the inability of the bituminous layer to respond to the repeated traffic loading also characterized by the increase in number and in magnitude of the transport vehicles. Fatigue cracking is one of the primary structural distresses modes related to the repeated application of traffic induced stresses.
The use of reinforcement interlayer in pavement structures is a well established methods to retard the occurrence of the reflective cracking; various types of products exist for mitigation which can include geogrids, woven, fabrics or composites systems. Despite the common employ of this techniques no data certain are available to estimate, in the rehabilitation design phase, which can be, quantitatively, the obtainable increase of life.
In laboratories, fatigue characteristic is usually assessed by repeated load bending tests done with three main configurations, trapezoidal beam test, three point and four point bending test fixtures with prismatic beam specimens. Four point bending is favoured since failure can starts in an area of uniform stress between the two centre loads.
The aim of this research is to investigate the fatigue characteristics of a bituminous material reinforced with typical geocomposites used commonly in road applications in Italy to evaluate the improvement, in terms of number of cycles, due to use of these materials.
The experimentation concerned a comparison made between asphalt concrete beams strengthened with a geocomposite reinforcement compared to a control material un-reinforced.
The preliminary step of the whole research was the individuation of the correct methodology for the sample preparation, an evaluation carried out investigating three different procedures.
The research was therefore structured according to a first phase dedicated to the execution of the test in a four point bending configuration, applying both a sinusoidal and an haversine waveform.
The second phase was focused on the tests analysis through two different analytical approaches to quantify the increase in fatigue life: classical approach and energy ratio approach.

A detailed slab preparation procedure

The preliminary step of the research regarded the analysis of methods to realize asphalt concrete slabs characterized by a nominal 5 cm thick finished beam with a percentage of voids of 5% ± 1 with a geocomposite reinforcement at the bottom of the beam.
This study considered three different procedures: a real scale field, a metallic mold method and the roller compactor method.
The first one foresaw the realization of a real double layer pavement with a geocomposite interlayer and the consequent sawing of reinforced beams.
The second one was characterized by the employment of a metallic mold filled with asphalt concrete and then compacted with a real roller to obtain reinforced slabs.
The third one, based on the use of a laboratory apparatus, allowed to obtain a sample preparation procedure free from all the negative aspects that characterized the previous methods for example high voids content and irregular thickness.
In light of these considerations the author deemed it the more proper procedure to the slabs preparation.

Four point bending tests

Fatigue tests were performed in controlled strain mode on couples each one characterized by a reinforced beam with a geocomposite and an un-reinforced one, at a temperature of 5°C and a frequency of 10Hz. The end of the test was assumed to occur when the flexural stiffness was reduced to 40 percent of the initial value, defined as the stiffness assessed at 100 cycles.
During the study were investigated two different experimental test setup: the sinusoidal and the haversine waveform.
In the case of sinusoidal waveform, from the analysis of the first comparison between reinforced beams versus un-reinforced, tested at 350 με, it was noticed that the four point bending test didn't emphasize a substantial difference but even in some cases it was highlighted a slightly better behavior in the un-reinforced beam.
A further observation was a random macro-cracks occurrence function of the local thickening of the beam. An event justified by the fact that, as well known, the sinusoidal load curve forced the beams to a bending stress both, at the bottom and at the surface side, the samples R were reinforced only at the bottom side (for a better coherence with the geo-composite real field of application) and by the presence of the intrinsic tolerances deriving from the compaction process.
Therefore it happened that the crack propagation started in the beam R from the wrong side (the un-reinforced top side), vanishing the evaluation of the role of the geo-composite in terms of increase in fatigue life. This led to the conclusion that the tests executed in such way weren't able to properly investigate the reinforcement efficiency.
The author deemed it appropriate to bend the beams only in one direction (haversine), causing tensile stress only at the bottom side where reinforcement was applied.

Test analysis

Fatigue life was evaluated according to two different methods: the first based on the stiffness reduction and the second on the energy ratio.
According to the first methodology, fatigue failure was defined as the number of cycles, Nf, at which the initial stiffness is reduced in to 40%.
The comparison between the reinforced and the un-reinforced beams, using the classical approach, was made as the ratio of the number of cycles of the reinforced and the number of cycles of the un-reinforced.
The analysis of the fatigue test results emphasizes that the reinforcement improved, on average, the entire life cycle of the samples of 2 times, but at the same time the data investigation underlined a high value of the Standard deviation (1.11) due to the fact that this approach took into account both the period before cracks initiation and the period during cracks propagation.
As regard the Energy Ratio approach the author intended to release the analysis from the initial characteristics intrinsic of the material, considering also the fact that the reinforcement started to work from the macro-cracks initiation and not before.
This was possible assessing the beam fatigue life only during the period of macro-cracks propagation (the Residual life - R_L); i.e. from the macro-cracks initiation (Ni) until the critical loss of modulus (Nf).
To define the number of cycles (Ni) where the macro-cracks are considered to start it has been used an Energy ratio Rn defined as the ratio between the cumulative dissipated energy up to the n-cycle and the dissipated energy at the n-cycle.
The comparison between the reinforced and the un-reinforced beams, using the energy ratio approach, was made as the ratio of the residual life of cycles of the reinforced (RL_R) and the residual life of the un-reinforced (RL_{NR})
The data examination gave emphasis that during the residual life of the specimen the geocomposite was able to quadruple the fatigue life retarding the reflective cracking occurrence.

Conclusion

This research allowed to carry out an evaluation of the effects on fatigue life due to geocomposite reinforcement of asphalt pavement.
The analyses executed on the fatigue test results demonstrated that a more proper evaluation of the reinforcement efficiency in terms of life cycle increase could be done investigating only the phase of macro-cracks initiation and propagation (Nf-Ni). Such assessment was possible using the energy ratio approach to determine the number of cycles Ni corresponding to the start of macro-cracks.
In conclusion, the use of the geo-composite reinforcement as rehabilitation method allowed to implement, on average, 4 times the fatigue life during the spread of the macro-cracks.

GNSS PERMANENT NETWORKS MONITORING: PROBLEMS AND SOLUTIONS

Stefano Caldera

In ‘80 and ‘90, zero order networks of GPS benchmarks were established in almost all the European countries, designed to disseminate the national datum with an accuracy of some cm for cartographic purposes. In case they have not been periodically resurveyed, neither displacements in time nor velocities have been estimated: as a consequence they can be defined as static networks, which materialize static reference frames (for example IGM95 is the Italian static network). To fully exploit new GNSS techniques, permanent networks have been set up in many European countries during the last twenty years, with the aim to provide positioning services to users, by the distribution of the coordinates of the permanent stations, their raw data and network products. By means of a continuous adjustment, a positioning service continuously monitors its station coordinates and dynamically materializes the reference frame, considering not only the smooth long term trends but also the possible sharp discontinuities.
This is not possible for the static networks, whose coordinates are not monitored. For this reason, permanent networks and related positioning services really represent the chance to continuously and reliably monitor the distributed coordinates. This is important not only for high precision applications but also for cartographic purposes, so that fundamental networks are migrating from the static to the dynamic realization.
Because of intrinsic reasons, a positioning service materializes the global reference frame but, considering that the most of its users need national cartographic coordinates, they should also estimate and distribute the transformation between the global and the national cartographic reference frames.
In the last years, GNSS positioning services are under development in Italy, both for real time and post processing applications; for administrative reasons, and in lack of any national planning or coordination, they are designed, created and managed independently. This organization represents a weakness: local neighbouring positioning services should guarantee the distribution of consistent reference frames, and this requires a national coordination.
At a first level, they should be adjusted and monitored in a unique zero order permanent network, by following a common adjustment protocol, exactly as it happens for the analysis centers of the international networks.
Moreover, an Italian national zero order permanent network could fulfil other aims: the first, and most important, is the transition from the old, deformed and static IGM95 to a new reference frame, continuously monitored in the global frame, that could provide very accurate time series of coordinates. At last, the availability of global and cartographic coordinates and velocities for a zero order permanent network would allow a national estimate of the transformations between the two frames, at any reference epoch. The distribution of an official, unique national transformation to the user community would prevent local, independent choices, that typically lead to inconsistent results. In Italy this transition became a reality at the beginning of 2009, when an Italian zero network was officially adopted (Rete Dinamica Nazionale, RDN): this has been possible also thanks to the researches presented in this dissertation. In particular, after a work where it was demonstrated that an Italian zero order network would be feasible with minimal hardware costs, the author has been significantly involved into the official realization as a member of one of the two independent cross-validation centers: in particular, the author’s contribution was the RDN network adjustment and the quality check of data and results. The adjustment and the quality monitoring was automatically performed using the RegNet software, whose development and improvement required a large part of the Ph.D. activities. In fact, in order to guarantee maximum reliability and accuracy, a permanent network must monitor its station coordinates by a continuous adjustment and quality check.
The final adjustment, finalized to the estimation of the permanent station coordinates, is generally computed by daily adjustments of the network; the process requires a large number of operations, from the data download to the coordinate estimation; obviously, for the continuous monitoring, a software able to automate the whole process is needed; beyond the technical execution of the continuous adjustment, it should also provide a series of quality indexes and relevant statistics that are useful to check the quality of the data and to improve the results; moreover, the time series should be analyzed to identify discontinuities and long term trends. Obviously RegNet was not the first package to automate the processing of a permanent network; nevertheless, its interest is exactly in the computation of quality indexes and in the creation of relevant statistics, that allow to identify the main station problems and to enhance the adjustment results.
The experience matured in the monitoring of two permanent networks aimed at positioning services (GPSLombardia, at the Italian Regional scale and composed of 16 permanent stations, and ItalPoS, at the national scale and composed of about 150 stations) permitted to test and tune RegNet software and to analyse the strategies for the adjustment of local networks. Moreover, the need of positioning services to compute and distribute the transformation between ITRS (at present ITRF2005) and ETRS89 (in the past ETRF89-IGM95 and at the present ETRF2000-RDN) permitted the study of the problems related to this transformation at the Regional and the national scale. On this regard, particular attention has been paid on its computation approach, providing alternative solutions for all national or Regional positioning services with different observation sets, and on the stochastic analysis of the deformation field of IGM95 with respect to ITRF2005.
The last analysed problem is relevant to the network splitting and recombining in the daily/weekly adjustment, i.e. the so called Helmert Blocking or Normal Equation Stacking. For example, the quick growth of the number of stations of ItalPoS raised the problem related to the technical impossibility to perform a Batch adjustment of a network composed of more than 200 stations; normally, in this case the network is split into significantly overlapping subnetworks, that are separately on the daily basis and finally recombined (COD approach): in this way the correlations due to the overlaps are ignored and false independent redundancies are introduced; this error does not affect the coordinate estimations but involves a significant underestimation of the covariances. An alternative approach (VAD) has been discussed, based on a variable configuration of the subnetworks, that are connected each day just by one station.
The alternative approach has been tested on a case study: four weeks of a network of about 100 permanent stations belonging to the European EPN network have been adjusted with the three different approaches (Batch, COD and VAD).
The VAD approach requires a significant coordination between the processing facilities but the results on the test network show that it provides accuracies and estimates very similar to those obtained by the Batch rigorous adjustment: this is true also if the daily VAD subnetwork configurations are randomly generated and not optimized.
More analyses on some optimality criterion will be performed in the next future.

COMMUNICATING THE CULTURAL HERITAGE USING PHOTOGRAMMETRY

'Box – systems' for spatial data within virtualized environments as a methodology for preventive conservation and maintenance

Branka Cuca

The task of describing something that already exists was always considered to be a major challenge because of the important role documentation and archiving of any historic, archaeological or architectural entity. Their continuous metamorphose, a material or a spatial change, requires to keep into account the fourth dimension of time. The up-to-date surveying techniques and continuous methodology development enable us to almost fully describe any study case considered, through the creation of highly faithful models of reality.

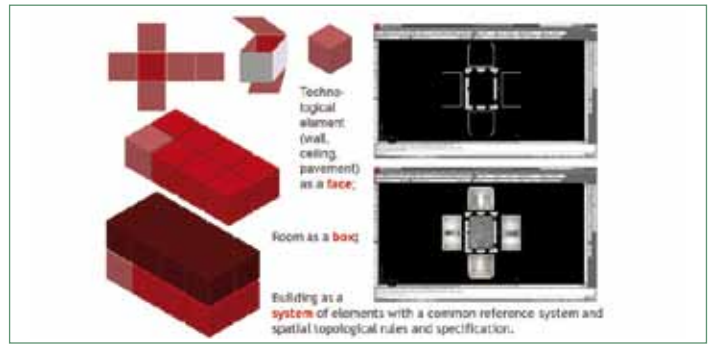
The aim of this research was to make an overview of the possibilities, limits and further perspective of photogrammetric disciplines in communicating cultural heritage, observed from two points of view – one as a technical and critical judgment towards technologies and another concentrated on the representation and information communication, often seen as the end product and not as a mean for further dialogue and interpretation.

The volume illustrates different methodologies in data acquisition, processing and dissemination using as a study case a large complex of Villa Reale in Monza. Close-range photogrammetry and laser scanning survey technologies were performed to deliver high precision detailed models, used for the heritage digitalization and virtualization. All architectonical elements are represented by geometric drawings, rectified images and orthophotos with up to a 2mm ground pixel resolution. Orthophoto construction was in some cases aided by surface models obtained from laser scanner data, confronting difficulties in the area of Object Recognition and Reconstruction (ORR), typical of complex surfaces such as the case of heritage scenarios.

The objectives of the study were on one side to improve remote access to 3D data that in the future could support advanced programs of preventive conservation and guarantee a sustainable intervention and maintenance; on the other hand, most suitable dissemination methods were explored to facilitate knowledge diffusion to public users through a web vehicle. A management model that fully follows the monuments' life-cycle was conceived as a methodological and operative work environment capable to continuously inherit the information even after the planning phase. The model proposed is based on a concept that sees every element as a face of a cube – every room was "broken down" into six single elements (walls, pavements and vaults). Every face is a reality on its own but also in a spatial relationship with others, with no restrictions on number of faces or their shape. 3D CAD models were constructed, texturized and enriched with details using survey data.

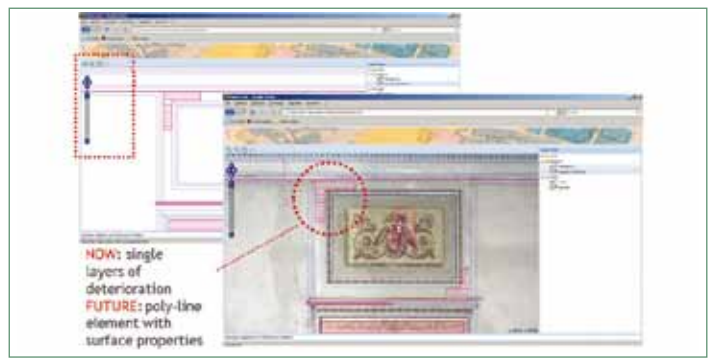
A Virtual Museum prototype was developed as a space for survey data collection and to bring closer the monument to general public, but also to offer a remote data consultation tool to professional users.

The technical architecture of the web service offered, compliant with most recent Open Geospatial Consortium standards, includes metadata, spatial data sets, and network services within a layered architecture: User interface layer (applications and Geoportals), Service layer, and Data Sources layer. A catalogue service is still not available but its development is foreseen, as it is an essential element for any dynamic database interaction. The first prototype version did not contain any spatial reference but recent implementation permitted to consult all survey material in geo-referenced environments. A particular visualization tool enables a user to track down the coordinates of any point within the single element and hence make measurements of distances or areas. Object coordinates are in a spatial relationship and coherence, connecting all the elements into a same spatial reference system – a "box-system".



1. 'Box-system' as a tool for spatial data organization

2. Box-system' web page within prototype website of Virtual Museum of Villa Reale in Monza



3. Web-portal visualizing tool in a geo-referenced environment

3D model representation of cultural heritage is in general often limited to simplifying objects into planes or elements with no full respect of their inter-relationship. Future work could therefore meet the need of an intelligent model with a dynamic geo-database, able to have a flexible reference system, able to correlate properties and coordinates of all elements of the system, establishing an intelligent dialogue. A permanent and consistent bilateral information flux using web-service could be essential for interdisciplinary collaboration in remote, but also for public awareness rising, guidelines definition and policy making.

IMPROVING ASPHALT CONCRETE PERFORMANCE: EXPERIMENTATION ON ROLE AND POTENTIALITY OF FIBERS

Edoardo Mariani

In recent years, the definition of new principles for road infrastructures design and construction became a key goal for both scientific and technical research, becoming high performance and resources optimization focusing factors in road management. Road pavements indeed are called to resist increasing stresses due to traffic frequencies and loads. In order to guarantee the required performance and the reduction of common pavement decay phenomena (rutting, cracking, graveling, etc…), at the present time road engineering research focuses its attention on the set up and the development of new bituminous mixtures able to provide suitable specific performance through both the use of well known solutions, opportunely combined, and the development of innovative materials.
Fibers play a fundamental role in this innovative context, being an innovative resource for asphalt pavements in the light of the experience developed with fibro-reinforced concrete. The addiction of fibers to the concrete mix represents in fact a fifty years well-known technology. Mixed with the cement concrete, fibers allow the creation of a secondary reinforcement net able to prevent shrinkage cracking during curing phase.

In asphalt concrete mixtures instead, the addiction of fibers has a "secondary" function avoiding the drainage of bitumen during the production, the storage, the transport and the laying-compaction of some defined mixtures (splittmastix asphalt and open-graded wearing course), thanks to the shown absorption properties.
The presented experimental research activity was developed, according to previous considerations, with the aim of understanding the role and the functions performed by fibers into asphalt concrete, identifying the possible critical states due to a wrong and uninformed use of these additives and finally discovering tricks to make the most of capacity of this technology.
The preliminary step of the whole research was the analysis of scientific and technical experiences, both in European and International contexts, concerning fiber reinforced asphalt for road and airport pavements, allowing the definition of the proper laboratory activities necessary to gain the required data necessary to give an answer to fixed targets.
The research was therefore structured according to a first phase dedicated to the analysis of the rheological behavior of bituminous mastics added with fibers, in order to understand how these could affect mixing and laying phases of bituminous mixtures, and a second phase focusing on the examination of the behavior of fiber reinforced asphalt mixes, not only from a volumetric and traditional mechanical point of view but also from an innovative mechanical characterization through dynamic tests.

The influence of fibers on bituminous mastics characteristics

The first step of the research regarded the analysis of the rheological behavior of bituminous mastics obtained mixing bitumen, filler and fibers. The rheological behavior of each considered mastic was characterized through both traditional experimental tests (penetration test and softening point test) and rheological analysis (determination of dynamic viscosity through rotational viscosimeter).
Viscosity was particularly analyzed in consideration of different test temperatures in order to define the viscosity ramps, curves relating viscosity to temperature.
The experimental analysis showed an increase of the softening point of mastics according to the fiber content and a consequent reduction of the sinking value determined through penetration test.
It was also observed an increase of viscosity according to temperature reduction, with a consequent stiffening.
The viscosity ramps were subsequently subjected to further analysis for the evaluation of the mastics natural thermal stiffening aptitude and the influence of fibers on the optimal temperatures for each different working phase of fiber reinforced asphalt concretes (Equal Viscosity Temperatures).

The influence of fibers on asphalt concrete

The second phase of the present research focused on the investigation of the role and the function of fibers in asphalt concrete, according to different types and contents and considering two different bituminous mixtures: a dense graded asphalt binder layer and an open graded wearing course.
In order to reach the described objectives, the experimental activity was further on split into three sub-steps: the first related to the design of the aggregates mix, the second concerning the optimization of the optimal bitumen content for each analyzed mixtures, through volumetric/mechanical mix-design, and the third aiming at the evaluation of the effects of fibers added to mixtures, according to four different types of fibers, changing their rate referred to the weight of bitumen.
First of all the volumetric characterization, based on specimens manufactured with two different compaction techniques (Marshall Hammer and Gyratory Shear Compactor), pointed out the substantial invariance of volumetric characteristics in relation to type and content of fibers variation thanks to application of the Equal Viscosity Temperatures for compaction.
The subsequent analysis was carried out for the determination of the mechanical behavior of fiber reinforced mixtures and was developed through both traditional tests (Marshall and Indirect Tensile Strength) and dynamic tests (Stiffness Modulus, Fatigue and Rutting).
The results showed a significant performance improvement due to the presence of fibers.

Conclusion

The analysis was based on a restricted, but certainly representative, number of fibers typologies, however it's possible to draw some general considerations. First of all the use of these additives allows a significant performance improvement, comparing to traditional mixtures.
This technology can be considered as a good answer to the pressing request of high performance and decay slowdown. It seems also clear that potential advantages pointed out by the research are reachable only with an aware and informed use of fibers, fibers in fact can also be a weakness for pavements without the respect of important tricks during construction phases.

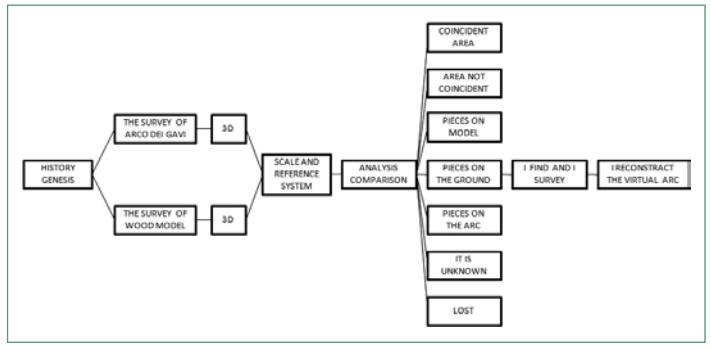
COMPARISON AND ANALYSIS OF THE ARCO DEI GAVI AND ITS MARQUETTE

Digital application and repositioning of the offside pieces"

Paolo Vernier

The modern geomatematics, supported by advanced instruments, both hardware and software, offers to Cultural Heritage new opportunities and interesting applications.
These application are strictly related to preservation, recovery, restoration and reproduction of the prototype, but also to the digital and virtual design on monuments that cease to exist and also to cataloging and to measurements' study of handworks. The possibility to obtain a 3D data, a model similar to the reality but also not linked to its fixed system, enables to realize studies that sometimes are too complex or impossible. In this chase of study, the wooden model has a specific and important function: it's a database for monument's reconstruction, it's a three-dimensional memory of a dismantle architecture, and it helps the architect who will reconstruct the monument.
Objects analyzed by this thesis are the Arco dei Gavi, an architectural monument built during the I sec. A.C., that was destroyed in 1805 by the Napoleonic's army, and his wooden model that was realized in 1813 and it has a very important role concerning on the monument's rebuild.
New technologies, applied to surveying, consent to obtain and analyze different object that however should be the same representation of Arco dei Gavi. The purpose is to realize two three-dimensional model comparable each-other, two models which consent to recognize differences, similarities and discontinuities about shapes and pieces that compose the monument.
Another aspect of this work is the location of outstanding pieces which are part of the original structure. The three-dimensional model helps to identify this identification and to reach this target the principal steps where be:

- Collect the documentation about the history of Arco dei Gavi and its representations
- Selection of proper instruments and software
- Survey of the two objects
- The definition of a reference system
- The rototranslation with a variation of scale to make comparable models
- The verify of the possibility to compare models
- The choose of a three-dimensional representation to emphasize the obtained results
- The reallocation of out standing pieces



1. Scheme of thesis

The most important choice was on correct instruments for the survey of so different objects which are unlike both for materials and dimensions.
In fact the wooden model is realized for a scale of 1:10 in comparison to the original.
The pourpose is to use instruments which give a similar result working to reproduce an image at the same scale, and so to produce comparable standard deviation.
The final instruments are a Riegl terrestrial time of fly laser-scanner LMS-Z390i for the architectural survey and the triangulation based ScanProbe LT (ScanSystem) for the wooden model.
The difference between two instruments is similar to the difference between models.
The metrical data is the key for the comparison and to accomplish a data usefully and complete of Arco dei Gavi were necessary three different scans for each main facade and two scans for lateral ones.
Looking at the inner part of the monument, it was necessary to make 5 scans with a different vertical axis. The changing's axis was very important to acquire the complete area.
From the point clouds obtained, the surface model of Arc was realized.
In the same way for the wooden model about 150 scans are done. Each single scan is made by 500.000 points.
The structure of the object, scans's number and survey's accuracy demand a bigger control on registration of clouds into the same reference system
The ICP algorithm, which is present in the software Geomagic 10, is the one used for this part of the work but to escape from drift problems a photogrammetric support was necessary.

The reference system, which is define from photogrammetry,

2. Mesh of Arco dei Gavi

3. Mesh of wooden model

4. Comparison of two mesh

is the unique system and it is the one used to compare surface models. Using the ICP algorithm another comparison between surfaces was done, looking especially to scale's variation.
All results confirm the geometric similarity of two object, even if the surface's comparison showed some problems derived from the data lack of some reconstructed parts.
So it's possible to admit that the methodology used until this phase of research make possible to obtain two comparable three-dimensional data.
The comparison was possible also for the software's, that sometimes had made easier the work. Working on data grid and using a 3D mesh, it was possible to elaborate each single surface verifying the macro area but also the single piece. The 3d reconstruction made possible to realize the actual form of the arc. However the reconstruction is correct looking at survey and at measures, but nothing about history and archeology has been considered. A future work should be to analyze the arc to transform the surface model into a solid model to create a three dimensional database useful to analyze each single piece with his history.
Also to find the ancient aspect of the Arc repositioning the outstanding pieces.

THE MIST EXPERIMENT: ESTIMATE TROPOSPHERIC DELAYS FROM A LOCAL GPS NETWORK

Grazia Visconti

In the GPS data adjustment, the tropospheric delay affecting the single satellite-receiver signal is modelled as the sum of a hydrostatic part plus a non hydrostatic or wet part: the hydrostatic part is described by models like the Saastamoinen one; it is considered known and it depends on meteorological parameters and on the height of the station; the non hydrostatic or wet part is described by a linear model depending on an unknown parameter representing the delay along the zenith direction above the station, the so called Zenith Tropospheric Delay (*ZWD*), multiplied by a known coefficient, given by a mapping function, projecting the *ZWD* in the satellite-receiver slant direction.
From the analysis of the double difference observation equations analysis results that in a local network it is not possible to estimate absolute coordinates and tropospheric delays of all the stations involved in the network without fixing the coordinate and the tropospheric delay of one of them.
Furthermore, only an hourly average of the *ZWD* parameter is possible.
With this consideration it was possible to set a strategy for the MisT network adjustment.
In particular we chose to use a sequential processing strategy: first the coordinate and the absolute tropospheric delay of the Como permanent station were determined, by a proper adjustment of the Lombardia GPS permanent network, then the Mist local network adjustment was performed using the Como permanent station as reference.
A significant part of this thesis work was dedicated on the choice of an appropriate strategy for the local GPS network adjustment; two different methods were compared: the first method following the guidelines suggested by the EPN (European Permanent Network) for regional network adjustment, uses the L3 Ionospheric Free frequency and QIF (Quasi Ionospheric Free) ambiguity resolution method; the second one, following the guidelines for local network adjustment, uses L1 frequency and SIGMA ambiguity resolution method. The quality of the two data adjustment was assessed on the basic of the percentage of fixed ambiguities and the final σ^2_0 estimate. The comparison between the two methods, performed on a monthly data set, led to the following conclusions:

- the time series of the coordinates estimate using the two strategies differ for a bias;
- although the SIGMA method slows the highest percentage of fixed ambiguities, it presents a final estimated σ^2_0 higher than the one obtained with the QIF method;

the differences between the two series of tropospheric delays are considered statistically significant.
For these reasons we chose to use the QIF method for the MisT network adjustment.
The hourly *ZWD* estimated were then analyzed to assess the feasibility of a spatial stochastic prediction. In particular, we modelled them as a stochastic field depending on height, position and time.
In this field we separated the part depending on the planimetric coordinates only, treated as a residual field with homogeneous and isotropic increments. This field is characterized by an rms which varies between 5 and 16 mm, its spatial correlation is of almost 100% at a distance of about 100 m, it goes down to about 70% at a distance of about 10 km and disappears at a distance of about 50 km.
In order to derive tropospheric delay in the satellite receiver direction, the so called slant delay, we passed to the analysis of the residual of double differences adjustment.
These residuals contain a linear combination of the tropospheric anomalous delays with respect to the wet zenith tropospheric delay estimated during the GPS adjustment and projected in the slant directions through the Niell mapping function.
To do this, a least squares algorithm performing an epoch by epoch solution was implemented in MatLab; to eliminate the rank deficiency present in the problem and obtain an estimate of the anomalous slant residuals an hybrid Tychonov norm is minimized.
The sum of the slant delays obtained by the GPS adjustment plus the anomalous residual delays obtained by this last analysis represents the input of a tomography algorithm for the reconstruction of tropospheric refractivity field.

1. The Mist network: the external network

2. The Mist network: the inner network