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PhD Yearbook | 2022

Chair:
Prof. Stefano Mariani

DOCTORAL PROGRAM IN STRUCTURAL, SEISMIC AND GEOTECHNICAL ENGINEERING

Objectives of the Doctoral Program

Structural, Seismic and Geotechnical Engineering (SSGE) encompasses disciplines and techniques allowing understanding, modeling and controlling the behavior of: (a) structural materials (concrete, steel, masonry, composites, bio-materials, materials for micro-systems and metamaterials), (b) structural systems (from civil and industrial structures and infrastructures to bio-mechanical systems and micro-systems) and (c) environment-structure interaction.

Deeply-rooted in the Civil Engineering, SSGE focuses on environmental actions, either external (such as earthquake, vibrations, irradiation, wind and fire) or ensuing from soil-structure interaction. The methods developed within the domain of SSGE apply to different scales and different physical process and, as such, are of great importance also in other technical-scientific fields, whenever understanding and controlling structural and material behavior is necessary to guarantee design reliability and structural safety, as well as serviceability and durability. Many are the themes arising in connection to SSGE: from tall buildings and bridges to industrial bio-mechanical and micro-electromechanical systems; from off-shore structures and dams to the rehabilitation of hystorical buildings; from seismic design and structural dynamics to the behavior of geomaterials and new engineered metamaterials.

Within this framework, the main goal of our Graduate School is to promote the advancement of knowledge especially in the fields of: (a) innovation in structural materials and structures; (b) structural safety under highly-variable actions; (c) behavior of geomaterials and surface structures.

We pursue this goal by offering our PhD Candidates an advanced, research-oriented background, based on both the pivotal role of Structural Engineering and the multi-disciplinary nature of Seismic and Geotechnical Engineering.

Contents of the Doctoral Program

Attainment of a PhD in Structural, Seismic and Geotechnical Engineering is conditional to: a minimum of three full-time years' study and research activities; the development of a PhD thesis; the achievement of the minimum credits required in terms of PhD courses.

Candidates are offered a variety of advanced courses on different topics, including mechanics of soils, materials and structures; computational and experimental methods; structural dynamics and earthquake engineering.

The study plan includes courses and seminars given by scientists, experts and researchers active either at the Politecnico di Milano or in other Italian and foreign Universities, research institutions and high-tech companies.

During their studies, PhD Candidates should develop their own original research work, consistent with the main disciplines dealt with in the Doctoral program, which will be reported in the PhD thesis.

The thesis should clearly state the goals of the research work, explaining the relation with the state-of-the-art, the used methods and the original results obtained.

The PhD research is developed under the guidance of a supervisor.

In order to widen and improve their research experience, PhD Candidates are strongly encouraged to spend a period abroad in one of the many Universities and research centers related to the Politecnico di Milano.

At the same time, the PhD School supports foreign scholars to give short courses and seminars in Milan, so that our PhD Candidates can constantly benefit from the opportunity to interact with the international scientific community.

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PERMEATION GROUTING IN GRANULAR MATERIALS FROM MICRO TO MACRO, FROM EXPERIMENTAL TO NUMERICAL AND VICEVERSA

Katia Boschi - Prof. Claudio Giulio di Prisco - Co-Supervisors: Prof. Bruno Chareyre - Dr. Matteo Oryem Ciantia

Permeation grouting is a geotechnical stabilisation technique commonly employed to improve both mechanical and hydraulic ground properties. Its basic principle consists in low pressure injections aimed at filling soil pores by means of either microfine cements or chemical grouts, as nanosilica aqueous suspensions and sodium silicates, whose rheological properties vary with time until changing their consistency into a solid. Although this technique is very commonly employed, the micro-mechanical processes taking place at the local level and, consequently, the macro-mechanical behaviour are not yet totally understood and correctly modelled. Indeed, the design is currently derived from empirical approaches based on experimental observations. Moreover, uncertainties related to the injection process are still high and phenomena like shortfall in consolidation and consolidation occurring at unexpected locations often occur.

In this thesis, permeation grouting in granular materials has been investigated and modelled by means of experimental, theoretical and numerical approaches, taking into account the complex hydro-chemo-mechanical coupling which governs the occurring processes at the micro-scale. Laboratory tests contribute both to derive input data for the study and to validate derived theoretical models and employed numerical tools as well as these last allow to better explain experimental observations.

The permeation process (intended as pore saturation without any change in the soil microstructure) has been studied by mainly focusing on the influence of the grout mechanical behaviour, defined in terms of its time-dependent non-Newtonian rheology and particulate phase description.

More precisely, the rheology of several nanosilica aqueous suspensions and microfine cements, characterised by different grout compositions, has been firstly accurately investigated and described by means of a Bingham's law. Then, the permeation of these grouts throughout granular porous media has been modelled by modifying the well-known Darcy's law, being so capable of accounting for their time-dependent Binghamian rheologies. In the case of microfine cement injections, an upper limit value for the grout particle dimensions with respect to the fine fraction dimensions of the soil to be treated has been quantified in order to prevent filter-cake phenomena.

The occurrence of hydro-mechanical coupled phenomena also affecting the evolution of the soil micro-structure, which may have a not-negligible effect during permeation grouting treatment executions, has been accounted for by using discontinuum mechanics approaches, via discrete element method and its coupling with pore-scale finite volume one. These phenomena are: (i) suffusion, that is the finest particles washed out by seepage flows without any rearrangement of larger grains, expected when dealing with highly-graded soils, (ii) both cavity expansion and claquage, i.e. hydraulic fracturing, which start playing an increasing role for higher injection pressures.

The final goal is to provide an effective contribution not only in grouting treatment both execution and design, but also in the research and development of new products and technologies. Optimisations in these terms would also lead to an extension of application fields.

To this aim, predictive tools have been proposed to rationally optimise the injection process in terms of nozzle spacing, injection time, imposed flow rate and pressures, to appreciate the influence provided by different grout compositions as well as to anticipate the expected occurring phenomena.

Key words: ground improvement, permeation grouting, fluid injections into granular materials, non-Newtonian fluid-like material flows.

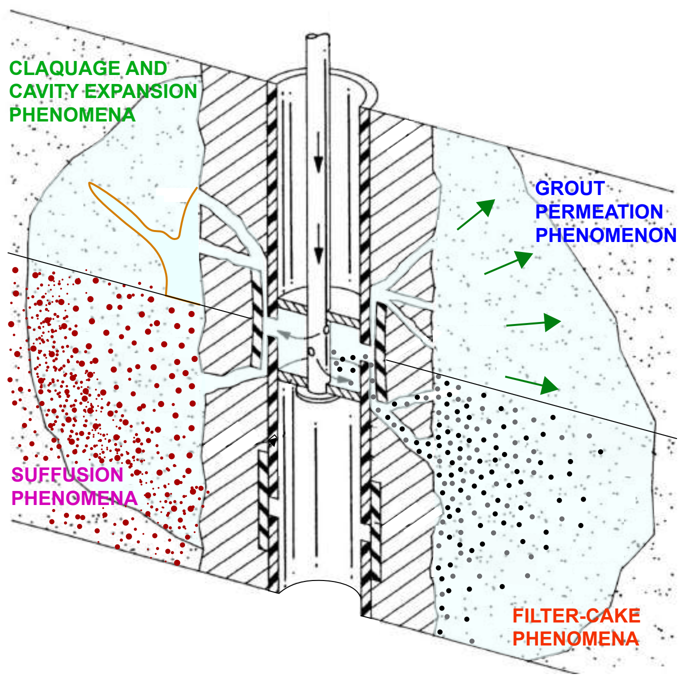

Fig. 1
Graphic schematisation of the main phenomena that can be faced during permeation grouting applications.

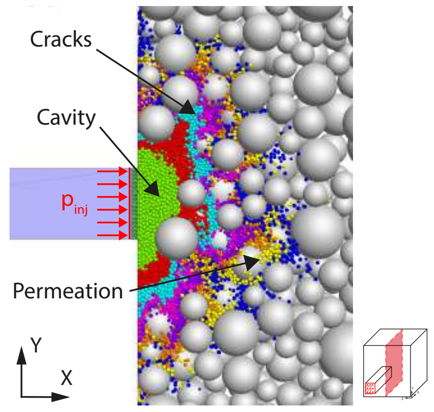

Fig. 2
Numerical simulations in which the simultaneous occurrence of permeation, cavity expansion and claquage phenomena as well as particulate grout characteristic length influence, leading to filter-cake phenomena, can be correctly captured by following a micro-mechanical discontinuum approach.which the simultaneous occurrence of permeation, cavity expansion and claquage phenomena as well as particulate grout characteristic length influence, leading to filter-cake phenomena, can be correctly captured by following a micro-mechanical discontinuum approach. vehicle

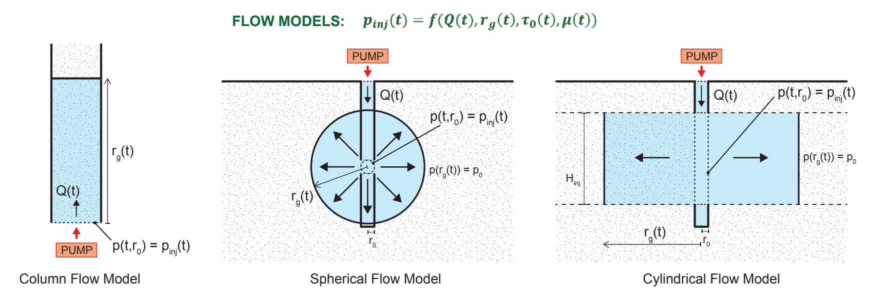

Fig. 3
Design tools: column, spherical and cylindrical flow models (simplified geometrical injection conditions taken into account to derive explicit analytical equations).first chicane of the Monza ENI Circuit.

LIMIT ANALYSIS FOR VAULTS AND DOMES OF HISTORICAL MASONRY HERITAGE

Maria Chiara Giangregorio - Prof. Dario Coronelli - Co-Supervisor: Prof. Giuliana Cardani

The scope of this dissertation is the study of masonry shell structures of historical heritage through the methods of limit analysis. The thesis aims to develop models for three-dimensional masonry vaults and domes, for use in the interpretation of observed crack patterns and to study the safety of these structures. The final aim is to set up computational tools that can be integrated with experimental observations within a multidisciplinary approach.

Discrete models are formulated, based on the two main theorems of limit analysis. Linear programming algorithms are used to calculate limit loads and mechanisms. Different codes are shown and described in the thesis. These can be grouped in two categories: kinematic and static.

The kinematic approach is developed to calculate the limit load and the three-dimensional collapse mechanism of shells using the discontinuity layout optimisation proposed for plane problems and slabs (Gilbert 2007). Symmetric and skew barrel vaults are analysed. The effects of strengthening with iron tie rods or innovative materials are examined as well.

A static model is developed, based on discrete blocks equilibrium (D'Ayala and Tomasoni, 2008) and the application of strength criteria at interfaces. This allows to study a cracked masonry dome structure, evaluating the collapse multiplier and mechanism by considering the shell flexural response mechanism. The static approach is used as well to analyse the actual behaviour of a dome on reaching the maximum load that the structure can withstand before cracking. Rotational double curvature domes and polygonal domes are compared.

The membrane regime analysis is used to carry out an investigation on the role of geometric parameters (span, crown, shell thickness, oculus and lantern) in the response of rotational domes for axial-symmetric loading. The parametric definition of geometry allows for an investigation of the proportions of the systems examined and to understand of the design of heritage structures.

Finally, the static approach is used to analyse a case study of a heritage building. The structural system of the dome supporting a tower of the Chiaravalle Abbey in Milan is studied, integrating observations carried out on the existing structure and the methods developed in the thesis.

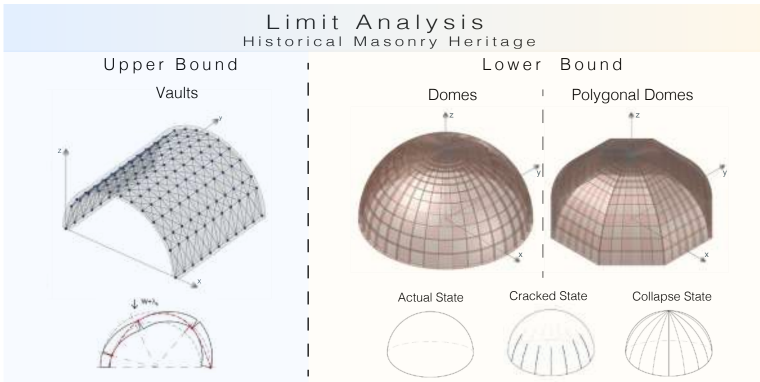

Fig. 1
Graphical Abstract

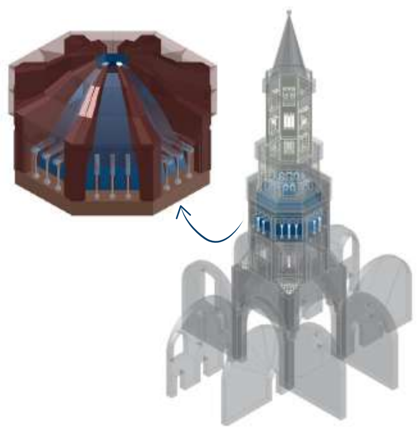

Fig. 2
Chiaravalle Abbey in Milan

The thesis is divided as follows: a first introductory chapter lays the foundations on the state of the art by introducing key concepts, such as limit analysis, the properties of masonry material and typologies of vault and domes with their characteristic geometry and typical crack patterns. These topics are then used in the following chapters, where the two main theorems of limit analysis are applied in discrete models that allow to automate the structural study of vaults and domes. The second chapter is dedicated to the description and application of the algorithm based on the kinematic theorem of limit analysis and inspired by the Discontinuity Layout Optimization, by Smith and Gilbert (2007), that allows to analyse different types of barrel vault up to collapse. The extension of DLO method to shell three dimensional structure is the first goal of the work, that concerns also the effect of structural strengthening considered in the analysis.

The third chapter is dedicated to the description of three discrete codes created on the basis of the static theorem of limit analysis which is applied to existing masonry rotational domes, in the membrane regime for crack condition, and in the flexural regime, that allows to analyse the collapse condition of a masonry rotational dome. The fourth chapter is dedicated to the description of the discrete codes created on the basis of the static theorem of limit analysis, which is applied to existing masonry polygonal domes, a particular typology of dome with single curvature and polygonal section, in the membrane regime. Finally, the fifth and the sixth chapters are dedicated to the application of the static discrete algorithms. The fifth chapter shows the applications of the code for rotation domes to some analytical cases and to some existing cases: the churches of San Nicolò l'Arena in Catania, Sant' Agnese in Agone in Rome and San Giorgio in Ragusa. The sixth chapter includes the analysis of the case study of the polygonal dome of the Chiaravalle abbey which supports the load of the Lantern tower. The analysis of geometry and materials is used as input to be included in the discrete algorithm and the application to Chiaravalle abbey also shows the information deriving from the crack pattern for the structural analysis. Furthermore, the different behaviour of a polygonal dome in membrane condition and after the cracked condition is analysed.

The work here presented is related to the goal of preservation of cultural heritage, it allows to calculate collapse condition, with collapse multiplier and mechanism, for shell masonry structure with the kinematic and the static method in flexural behaviour. Concerning the static solution, an analysis is also shown that considers the static behaviour and an equilibrated condition before and after cracking, this is done considering membrane behaviour and a tensile strength in the structure. Relating this to the crack pattern observation provides a useful tool to understand the state of safety of the structure. With a simple and quick solution different configurations of geometry are here analysed and compared.

Fig. 3
The churches of Sant' Agnese in Agone in Rome, San Nicolò l'Arena in Catania and San Giorgio in Ragusa

REDUCED ORDER MODELLING AND ANALYSIS OF INTERNAL RESONANCES, BIFURCATIONS, AND FREQUENCY COMBS IN MEMS

Giorgio Gobat - Prof. Attilio Frangi - Co-Supervisor: Prof. Cyril Touzé

Micro-Electro-Mechanical-System (MEMS) technology represents one of the major breakthroughs of the last century. The miniaturization of devices like e.g., sensors, actuators, and their integration with electronic boards allow introducing them into everyday instruments, like e.g., smartphones, computers, cars, gaming consoles, as well as cutting-edge technologies like e.g., augmented reality glasses, prostheses, self-driving vehicles etc. This technology and its applications are possible only if a MEMS device has predictable behaviour and a reliable working principle. For both requirements, the MEMS designer performs numerical simulations to assess the performance before the fabrication. Nevertheless, the micro-scale poses challenges, rarely observed at the mesoscale, that cannot be ignored. The low damping factors due to the near-vacuum encapsulation of most MEMS devices and/or the large displacements and rotations needed for a good input-output signal ratio lead to the nonlinear behaviour of the device itself. Predicting the nonlinear dynamic response of a device represents a challenging task due to the long computational time needed with standard simulation methods like e.g. the finite element method, non-linear interactions between modes and the existence of alternative states that onset from bifurcations. Instead of tackling these problems with expensive full order methods, it is possible to resort to suitable reduced-order modeling techniques i.e. methods that allow reducing the dimensionality of the original problem.

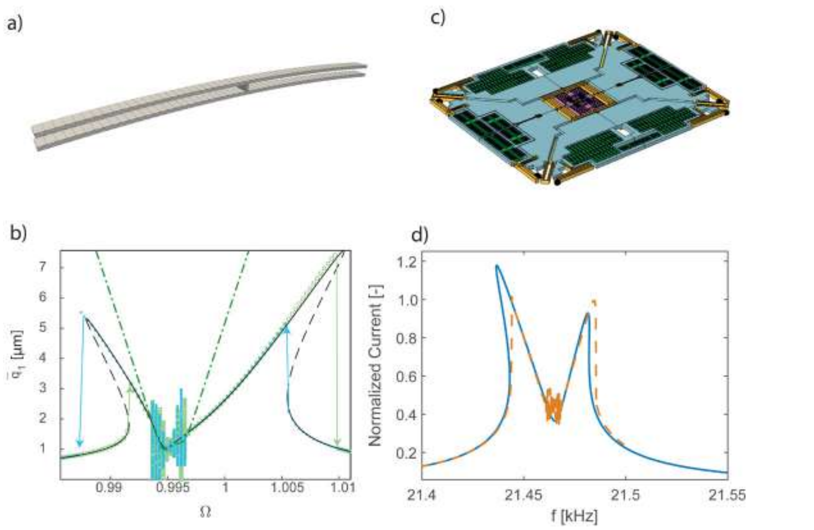

Fig. 1
In this thesis analytical techniques are used to investigate internal resonances in MEMS devices like the arch resonator in Fig. a). Such methods accurately reproduce the system dynamics Fig. b). Nevertheless, the system complexity may lead to an unfeasible application of analytical methods, e.g. the MEMS device in Fig. c), thus reduced-order modelling methods are used. These methods allow recovering the system dynamic response and match the experimental measures Fig. d).

This thesis contributes to the state-of-art of MEMS nonlinear dynamics analysis by presenting analytical models and reduced-order models tailored for MEMS resonators, internal resonances, and bifurcations. After a short introduction to MEMS technology, nonlinearities, and modelling we present analytical techniques for internal resonances in MEMS. Starting from the normal forms of 1:2 and 1:3 internal resonances, multiple scales method solutions are developed and tailored for MEMS-like problems. Thanks to this analytical approach not only the system response in the conservative and non-conservative cases is studied but also the bifurcation portrait is analysed. A focus is put on the so-called Neimark-Sacker bifurcation that generates a quasi-periodic regime with an associated frequency comb in the power spectra of the response. Later, two reduced-order modelling strategies are considered: the implicit condensation and the proper orthogonal decomposition. Both allow deriving a reduced-order model in the form of a system of nonlinear ordinary differential equations that reproduces

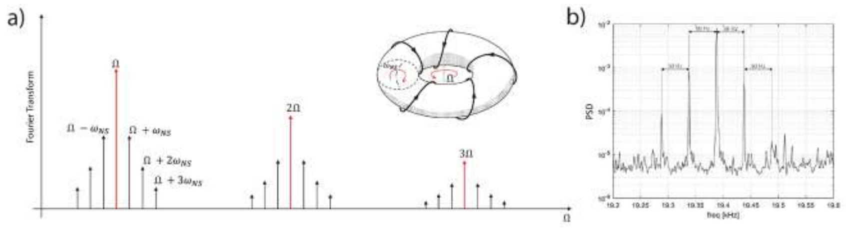

Fig. 2
The Frequency comb. Fig a) schematic representation of a Frequency Comb induced by a Neimark-Sacker bifurcation. The bifurcation introduces in the system response a new incommensurate frequency such that the Fourier transform of the system shows peaks at the forced frequency multiples and at each combination. This corresponds to a motion of the orbits on a torus in the phase space (qualitative representation in the top right corner). Fig. b) experimental frequency comb.

the MEMS dynamics. The former procedure, referring to geometric nonlinearities, uses a series of loads statically applied to the structure in order to identify the stress manifold of the system using one or very few low-frequency modes as a reduced basis. A similar approach can be used to reduce electrostatic forces contributions. In the thesis, first, the theoretical settings and the algorithm are detailed and next several applications are considered to address internal resonances, bifurcations and frequency comb. The results are validated against numerical and experimental data. Despite the flexibility offered by the implicit condensation method, the approach is limited in its application to moderate transformations. In systems where large rotations are present, e.g. micromirrors, this approach fails. As an alternative, we consider the proper orthogonal decomposition method. This technique is a linear reduced-order modelling method, which creates an ad-hoc basis thanks to matrices of snapshots of the solutions. Even though the proper orthogonal decomposition is well-known in the literature, its application to the field of MEMS is rather novel and reveals a remarkable performance. This contribution highlights both advantages and possible drawbacks and proposes an in-depth analysis.

SEISMIC ASSESSMENT OF EXISTING THREE-DIMENSIONAL RC BEAM-COLUMN JOINTS AND RETROFIT WITH FULLY FASTENED HAUNCHES

Angelo Marchisella - Supervisor: Prof. Giovanni Muciaccia

Post-earthquake surveys reported that severe shear damage localizes in the beam-column joint volume for seismic deficient Reinforced Concrete (RC) structures, especially in absence of horizontal reinforcement. Italian examples of building inventories show that aged RC buildings are becoming a new seismic vulnerable heritage. Counter-actions have a significant social cost. To put it elegantly, to retrofit or not to retrofit?

The Thesis was an effort to explore the mechanics of three-dimensional (3D) beam-column joint and assessing the feasibility of haunch retrofit solution. The research aimed at achieving a detailed description of the sub-assemblage behavior under seismic condition throughout analytical, numerical and experimental methods. The interest was limited to exterior joint with slab and transverse beam and corner joint with slab, both un-reinforced (the tested specimens are shown in Figure 1). Up to the date experimental studies addressed the problem of two-dimensional (2D) beam-column joints in most of the cases as it emerges from a wide systematic review of the literature. The most recurrent parameters studied by the researchers are: (i) joint hoops; (ii) anchorage conditions of the beam longitudinal reinforcement within the joint panel; (iii) continuous vertical reinforcement of the column passing the nodal region; (iv) column axial load; (v) joint aspect ratio; (vi) beam's eccentricity.

3D exterior joints, in as-built condition, exhibited torsional crack pattern for the transverse beam. The slab participation to the flexural behavior of the main beam was recognized as well. Higher strength and stiffness characterized the hogging behavior. Haunch retrofit was proved to be a feasible solution of strengthening leading the promotion of beam hinging. Slab participation induced ductility reduction and buckling of the compressed bars drastically decreased the rotational capacity in post-yielding phase. As per the haunch region shear cracks were not observed. Torsional cracks in the transverse beam were significantly reduced.

Corner joints were tested using hexagonal displacement protocol. In essence, the displacement demand in one direction (B1) was double with respect the other (B2). Joint failure in B1 has been recognized for the as-built condition characterized by X-shaped crack pattern. The joint lost completely its integrity (at side B1) at the end of the test, side B2 was severely cracked. A subsequent monotonic test for B2 showed reduced load-bearing capacity with respect to B1. Although the flexural crack pattern suggested slab's participation, strength difference in hogging and sagging behavior were not significant. Haunch retrofit was applied to one flexural plane only. This condition was inspired by a design case where the seismic demand in one direction (e.g. moment-resisting frame) is larger than the other (e.g. dual system). Results showed a significant reduction of joint distortion, if compared with the as-built condition. The joint integrity was preserved. Inversion of the (shear) cracks inclination has been recognized at the column face. Reduction of the strains in the beam's longitudinal reinforcement has been recognized passing from the end section of the haunch to the column face.

Given the shear nature of the beam-column joint stress field, which almost precludes the use of compatibility, results of the experiments were discussed privileging a force-based approach. Results show that (i) joint shear demand increases according to the increase of slab participation and (ii) confinement effect of the transverse beam led to higher shear resistance if compared with current design provisions. Larger strength characterizes exterior joints with transverse beam than corner. The torsional behavior of the transverse beam interacts with shear transfer and it has been proved with strut-and-tie model (SAT). Experimentally-derived torque moment was compared with analytical prediction suggesting the occurrence of yielding which was finally proven using 3D finite element analysis.

Influence of bi-axial condition for joint shear demand and strength remains un-solved apart from improved understanding and a new meta-analysis carried out on a database of corner joints tested bi-axially. The slab participation was studied comparing the analytical moment-curvature diagrams to the experimentally-derived ones. The former considered T-shaped and L-shaped cross-sections for exterior and corner beam-column joint, respectively. Results show that flange contribution leads both an increase of the hogging yield moment and a reduction of the ductility. Sagging behavior is less affected. Snap-back in the experimental curves was explained as a consequence of joint shear failure. Moreover, the slab participation jeopardizes the definition of the overstrength factor to the point that the adoption of modal-response-spectrum analysis becomes unpractical.

The state-of-the-art of structural analysis applied to beam-column joint retrofitted with haunch has been questioned. An application of SAT model was proposed instead. The geometry of the equivalent truss was chosen in such a way that the haunch was the only source of redundancy. The method was validated against the experimentally-derived internal forces. Further developments are needed to finalize a general parametrical solution.

The procedure for the retrofit of the sub-assemblage has been placed in the larger context of existing RC buildings assessment. A new design flow-chart, including three-steps analysis, was given.

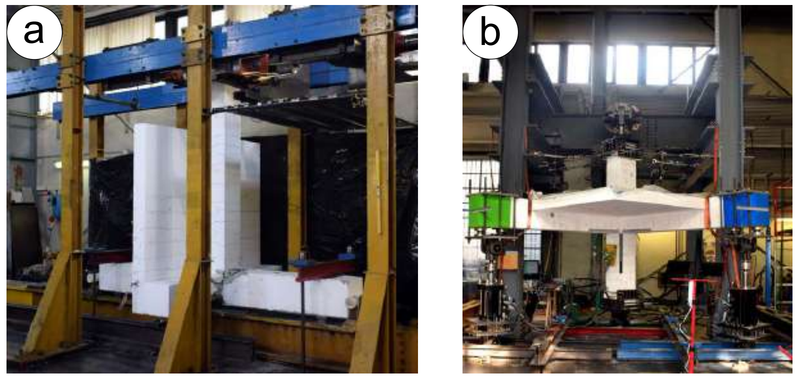

Fig. 1
RC beam-column joint sub-assemblage tested: (a) 3D exterior; (b) 3D corner.

PHASE TRANSITION IN GRANULAR MATERIALS: THEORETICAL AND NUMERICAL ANALYSES

Pietro Marveggio - Supervisor: Prof. Claudio di Prisco

The concept of "State of Matter" is one establishment on which the particles theory, popular in the in physics/ chemistry community, is based on. In that context, a distinction is made based on atomic particles interaction: matter in the solid state maintains a fixed volume and shape, matter in the liquid state maintains a fixed volume, but has a variable shape that adapts to fit its container, while matter in the gaseous state has both variable volume and shape. These definitions can be up-scaled, up to granular particles level, extending the concept of phase transition to granular materials. This aspect is central when studying granular materials mechanical behavior, due to their twofold nature: either acting as a solid (landslide inception) or flowing like a fluid (landslide propagation).
This thesis aims at interpreting these phase transition phenomena, initially considering dry conditions, in the light of strain hardening visco-elastoplasticity based on the critical state concept, interpreting this as a particular steady state under quasi static conditions, and kinetic theories of granular gases and demonstrating that crucial is the role of isotropic softening/ hardening describing the size of the elastic domain, that is the capability of the solid skeleton of storing elastic energy according to permanent force chains. The main ingredients of the model are: (i) the additivity of quasi-static and collisional stresses, (ii) the energy balance equation governing the evolution of the granular temperature, interpreted this latter as an additional internal variable for the system for the collisional contribution, (iii) the mixed isotropic and kinematic hardening characterizing the quasi-static incremental constitutive relationship.
The model has been both calibrated and validated on DEM triaxial numerical test results performed on dry assemblies of monodisperse spheres under true triaxial loading.
When saturated conditions are concerned, the presence of water changes the dynamics of the grain-grain interaction, producing additional dissipations due to grain-water contacts and the classic Terzaghi's effective stress principle should be redefined. Following the same approach adopted in case of dry conditions, the extension of the constitutive model is tackled starting from an energetic point of view, analyzing new mechanisms arising in case of saturated media are concerned. In particular, the grain-grain interaction is damped by the presence of the liquid phase, thus the energy dissipation of the granular phase increases since the particle movements are bounded by the liquid.
The dissertation is concluded by discussing the solutions of boundary value problems adopting the model previously conceived, implemented in a MPM numerical tool (ANURA3D), properly modified. These results, aimed at demonstrating the model applicability to real case problems, pave the way to the study of many geotechnical problems by means of a unique approach.

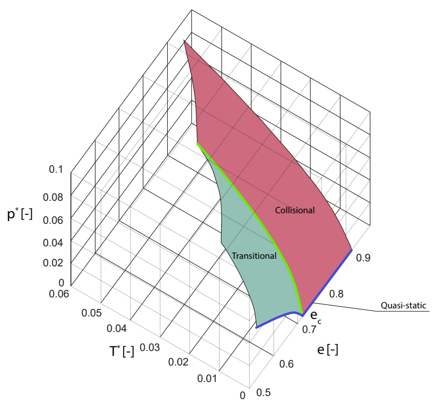

Fig. 1
State diagram for granular media

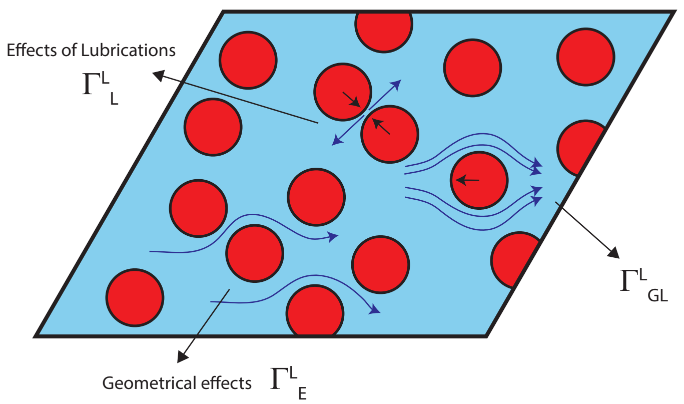

Fig. 2
Liquid contribution: dissipation mechanisms

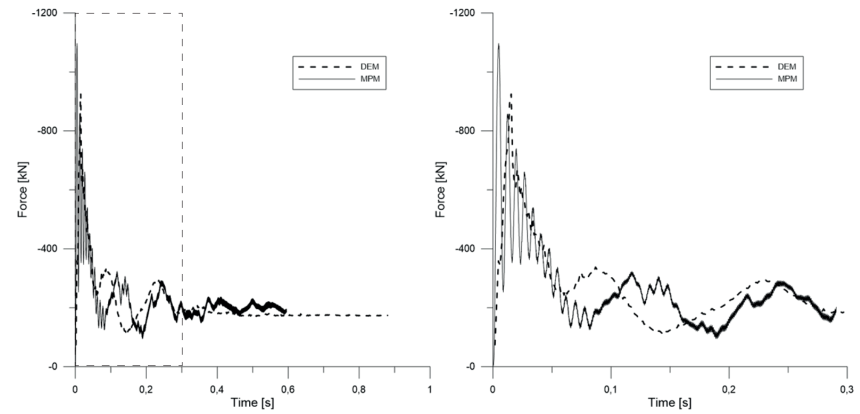

Fig. 3
Flowing mass impact on rigid obstacles: force vs time (MPM simulations validated against DEM results)

GLASS FABRIC-REINFORCED CEMENTITIOUS MATRIX (GFRCM) COMPOSITES: STRENGTHENING AND RETROFITTING OF EXISTING REINFORCED CONCRETE STRUCTURES

Marco Carlo Rampini - Prof. Marco di Prisco - CO-supervisors: Prof. Matteo Colombo - PhD Giulio Zani

In Italy, recent seismic events highlighted the vulnerability of a large part of existing buildings and infrastructures and the need to urgently promote their structural upgrading and/or retrofitting.
This growing interest has oriented researchers towards the optimization of high-performance cement-based composites such as Textile Reinforced Concrete (TRC), originally conceived for new lightweight constructions, and Fabric-Reinforced Cementitious Matrix (FRCM) composites, more recently developed for reinforcing applications. FRCMs, mainly used in the past for masonry buildings, seem to represent a promising solution also for the reinforcement of weakly reinforced concrete (RC) structures. Their main advantages, with respect to other reinforcement technologies like Fiber-Reinforced Polymers (FRP), are the better compatibility with irregular surfaces and substrate materials (concrete or masonry), the easier workability, the greater fire resistance, the vapor permeability, and the lower cost of application.

The thesis is focused on the investigation of the mechanical properties of FRCM composites and aims at evaluating and assessing the potential of this kind of reinforcement technology for RC structures, by means of a combination of multi-scale mechanical testing and simplified/numerical approaches.
In the first part, an extensive experimental campaign at the material (matrix, fabric, short fibers and composite) and at the meso-scale level was carried out (Figure 1), considering both monotonic and cyclic actions. Particular attention is taken on the FRCM performance optimization and to the study of the bond behaviour at the mortar-to-substrate interface, which plays a key role to guarantee the exploitation of the composite full capacity. This experimental approach partially follows the one proposed by the new Italian Standard and Guidelines, which allows designers to qualify FRCMs for reinforcing applications combining axial tensile and shear bond tests.
Then, in the second part, FRCM composites are applied for the upgrading and the restoring of different kind of reinforced concrete members (both integer and pre-damaged). The responses under both out-of- (beams and slabs) and in-plane (coupling beams) actions are investigated (Figure 2) and, in parallel, simplified and numerical approaches are developed with the aim to better understand the involved phenomena, to provide affordable tools for the design of FRCM reinforcing interventions and to suggest eventual modifications of the acceptance and qualification criteria contained in the current Guidelines.

From the results of both the experimental tests and the numerical simulations carried out in the thesis, some important conclusions can be drawn:
- the proposed definition of efficiency and ductility/energy absorption parameters represent a systematic approach to quantitatively compare the alternative available composites and to highlight the effect of each base material (e.g. the beneficial effect of the addition of dispersed short fibers on the mixture).
- The relation between the concrete substrate roughness and the bond capacity, confirms the necessity to define minimum requirements in terms of surface machining in the Guidelines, to guarantee the exploitation of FRCM composite performance.
- The proposed DEWS test may be considered a valid experimental method to investigate the effects of both the fabric orientation and the presence of an existing pre-damage state. Moreover, it conduced to a safe side estimation of FRCM capacity with respect to the one obtained by the combination of axial and shear tests, as proposed by the Italian Guidelines.
- At the full-scale level, the application of the FRCMs seems to be adequate to upgrade the capacity of the RC members (beams, slabs and coupling beams). Other beneficial effects of the composite applications are the crack control at serviceability, the partial restoring of the initial stiffness in case of pre-damaged members, and the control of the damage evolution in case of cyclic actions, maintaining the residual load bearing capacity almost unchanged.
Part of the thesis is carried out in the framework of the Italian ReLUIS inter-university consortium research, that also involves Politecnico di Milano. The purpose of this project is the proposal of technical regulations for the prevention and the reduction of seismic risks.

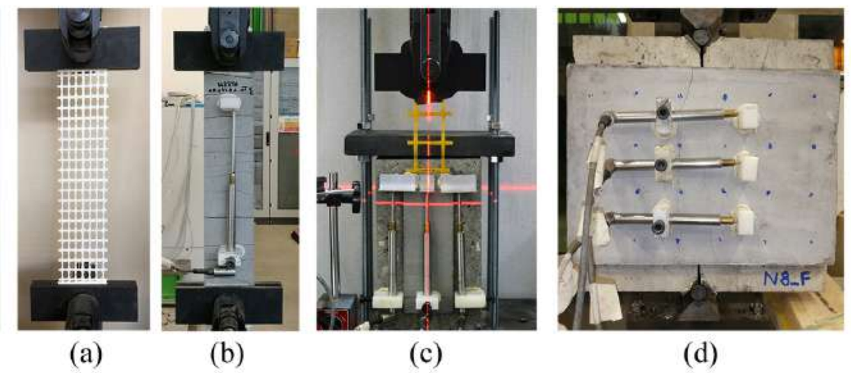

Fig. 1
Mechanical characterization from material to meso-scale: axial tensile test on plain fabric (a) and on FRCM composite coupon (b), shear single lap test (c) and DEWS test (d).

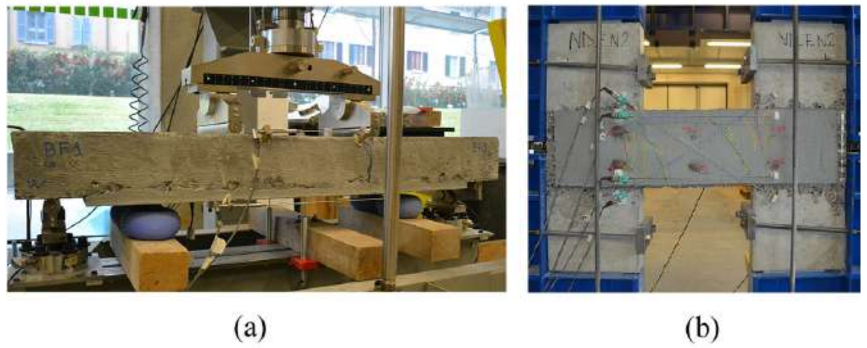

Fig. 2
Examples of full-scale test on FRCM reinforced elements: four-point bending test on shallow beam (a) and shear test on coupling beam (b).

STRUCTURAL HEALTH MONITORING OF OFFSHORE STRUCTURES USING DATA-BASED METHODS

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Structural Health Monitoring (SHM) is a growing and interesting topic in the offshore industry. The oil and gas industries are dealing with aging infrastructure and are looking for possible and reliable ways to extend the life span of these structures, whereas the wind energy industry is significantly investing on such structures. This makes a lot of unique challenges for health monitoring of offshore structures, which all come together with a significant concept known as uncertainty. These kinds of structures are highly prone to failure risk due to their uncertain environment and severe environmental variability. Moreover, many existing structures have not been monitored yet, and those have experienced various loading and operational conditions during their operational life, which are unknown. Due to the inaccessibility of many wind farms, typical inspection procedures are costly and, in some circumstances, dangerous. On this basis, SHM seeks to overcome these concerns by establishing technologies that enable an automated online evaluation of the state of structures to improve decision-making.

The main aim of SHM is to assess the integrity of these structures for early damage detection, damage localization, and damage quantification. In recent years, data-based techniques based on statistical approaches present efficient ways to diagnose damage by using measured vibration responses of structures. These approaches are generally based on two main steps, including feature extraction and statistical decision-making. Time series analysis and novelty detection approaches are effective tools for these steps. Despite the advantages of data-based damage detection methods, those may give unreliable results of damage diagnosis in terms of false alarm and false detection errors. These errors may lead to some challenging issues including inappropriate feature extraction, inaccurate feature classification for damage detection due to the adverse effects of environmental and operational variability as well as high-dimensional features. To overcome these challenges, this dissertation proposes data-based methods in the feature extraction and classification steps. The proposed data-based approaches are related to an iterative time series-based method for feature extraction, a robust multidimensional scaling-based method, and a clustering-based novelty detection approach for early damage detection, damage localization, and damage quantification.

Eventually, experimental and real structures are investigated to validate the efficacy and accuracy of the proposed approaches. The results indicated that the methods described in this study are reliable and effective solutions for SHM of civil and offshore structures under ambient excitations and environmental and operational variability.

Keywords: Structural Health Monitoring, Offshore Structures, Statistical Pattern Recognition, Time Series Analysis, Damage Diagnosis, Clustering Analysis, Robust Multidimensional Scaling, Big Data