MECHANICAL ENGINEERING L PHYSICS L PRESERVATION OF THE ARCHITECTURAL HERITAGE I SPATIAL PLANNING AND URBAN DEVELOPMENT I STRUCTURAL SEISMIC AND GEOTECHNICAL ENGINEERING I TECHNOLOGY AND DESIGN FOR ENVIRONMENT AND BUILDING I TERRITORIAL DESIGN AND GOVERNMENT I URBAN PLANNING. DESIGN AND POLICY I AEROSPACE ENGINEERING I ARCHITECTURAL AND URBAN DESIGN I ARCHITECTURAL COMPOSITION I ARCHITECTURE. BUILT ENVIRONMENT AND CONSTRUCTION ENGINEERING I ARCHITECTURE, URBAN DESIGN, CONSERVATION OF HOUSING AND LANDSCAPE I BIOENGINEERING I DESIGN I ELECTRICAL ENGINEERING I ENERGY AND NUCLEAR SCIENCE AND TECHNOLOGY LENVIRONMENTAL AND INFRASTRUCTURE ENGINEERING **IINDUSTRIAL CHEMISTRY AND CHEMICAL** ENGINEERING I INFORMATION TECHNOLOGY **I INTERIOR ARCHITECTURE AND DESIGN I** MANAGEMENT ENGINEERING I MATERIALS ENGINEERING I MATHEMATICAL MODELS AND METHODS IN ENGINEERING

PhD Yearbook | 2017



DOCTORAL PROGRAM IN STRUCTURAL SEISMIC AND GEOTECHNICAL ENGINEERING

Chair: Prof. Roberto Paolucci

Objectives of the Doctoral Program

Structural, Seismic and Geotechnical Engineering (SSGE) encompasses the disciplines and techniques that allow to understand, model and control the behavior of: (a) structural materials (concrete, steel, masonry, composites, bio-materials and materials for micro-systems), (b) structural systems (from constructions to bio-mechanical systems and microsystems), (c) soils and (d) environment-structure interaction. Deeply-rooted in the Civil Engineering, which is in itself highly interdisciplinary, SSGE focuses also on environmental actions, either external (such as earthquake, vibrations, irradiation, wind and fire) or ensuing from soil-structure interaction (such as those caused by retained-earth thrust, landslides and water-table fluctuations). Due to their generality in materials and structural modeling, the methods developed within the domain of SSGE can be of great importance also in other technicalscientific fields, whenever understanding and controlling mechanical aspects 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 monumental buildings; from seismic design and structural dynamics to slope stability, tunnel behavior and foundations, not to forget the topics shared with some branches of the Industrial Engineering.

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 materials and structures; (b) building safety under highlyvariable actions; (c) stability of soils and surface/buried 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: minimum three full-time years' study and research activities; the development of a PhD thesis; the fulfillment of the minimum

requirements provided in terms of PhD level 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.

As a consequence, great attention is given both to fundamental topics, still highly-debated within the scientific community, as well as to applicationoriented themes, which are of much interest for public and private companies, designers and academic institutions dealing with structural safety, reliability and the environmental impact of structures. The study plan includes courses and seminars given by scientists, experts and researchers active either at

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, coherent with the

main disciplines dealt with in the Doctoral program, which will be detailed 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 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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OF THE STRUCTURAL SAFETY OF HISTORICAL METALLIC TIE-RODS

Bellanova Mariagrazia - Supervisor: Prof. Roberto Felicetti

The main aim of the present research is the assessment of structural safety of ancient wrought-iron tie rods, with special attention to the Duomo di Milano case study. Due to their respective metalworking techniques, modern and historical ferrous metals can be considered two completely different materials in terms of heterogeneities, flaws density, size and typology of defects, microstructure, superficial conditions. These features strongly influence both the mechanical behaviour of the material and the applicability of many Non Destructive Techniques (NDTs). Although the modern metals have been widely studied in the recent decades, the knowledge on historical metals is very limited. A suitable strategy for structural analysis of historical metallic components such as tie-rods is not still available. Many techniques allow the estimation of the state of stress but they are not sufficient to provide a complete assessment because dominant defects are not taken into account. In order to satisfy the aim of the thesis two main topics have been studied: material characterization and Non-Destructive diagnostic. Concerning material characterization, historical wrought iron is a very heterogeneous material and

many defects can be recognized at micro, meso and micro scale. Therefore, many combined techniques commonly used in archaeometallurgy have been employed to study material features influencing mechanical behaviour of the final object and the applicability of the NDTs. Achieved results reveal that material is extremely heterogeneous in terms of both microstructures and defects. A good agreement between hardness tests results and microstructural findings has been shown. Distinctive hardness values related to the recurring microstructures have been estimated. Different types of flaws have been identified and characterized.

Based on these insights, a traditional mechanical characterization approach, such as by using tensile tests, is not reliable due to defectiveness. Since dominant macroscopic discontinuities have been identified by ET (i.e. forged welding), fracture mechanics has been considered the most suitable approach to estimate mechanical properties. A complete agreement has been found between results coming from fatigue crack growth rate testing and the plain strain fracture testing. This indicates that the global behaviour in terms

of toughness is not strongly affected by heterogeneities. In any case results of Linear Elastic Fracture Mechanics tests reveal that this approach is not reliable owing ductility of the material. For this reason, Elasto Plastic Fracture Mechanics tests have been performed to account plastic deformations. Most of samples have been obtained from undamaged original material; several of them are cantered on forged welding. Comparing results, mechanical behaviour is dramatically different: samples with welding joint are characterized by I-integral one order of magnitude lower. As regard non-destructive diagnostic, all established techniques are able to estimate tensile force but unlikely allow defects detection. Nowadays techniques specifically designed to detect flaws in historical metallic elements are not available. Different NDTs are commonly used in the aerospace and mechanical engineering, but their applicability on historical artefacts might be affected by many drawbacks, which might compromise their effectiveness. Therefore, many of them have been studied and calibrated in order to define a multiscale approach enabling dominant flaws detection in historical elements.

Guided waves method:

an ultrasonic tomographic device has been evaluated to acquire experimental raw data by setting delay to limit any initial overlapping. Based on an adequate shifting and recombining of waves coming from each transducers, a data post-processing procedure has been implemented to recognize cracked tie-rods.

Magnetic flux leakage

inspection: both experimental tests in laboratory and numerical simulations have been performed in order to evaluate the sensitivity of method. Configurations enabling crack detection generate attractive forces, which can be very dangerous to manage. For this reason, method has been considered not suitable to purpose of the thesis.

Eddy current testing: after preliminary inspections on original samples by using three standard probes coupled with a common eddyscope, two customized probes have been designed and realized in order to obtain the pursued test performances. They allow the clear identification of forged welding between wrought iron pieces.

Active thermography: numerical simulations and experimental tests have been performed in order to evaluate the effectiveness of the application on historical tie-rods and the most suitable test configuration. Results are promising and reveal some potentialities at the intermediate scale of diagnosis. Based on studies developed in this work combined with other established methods, it has been possible to define a multiscale procedure to perform a complete assessment of the structural safety of historical metallic tierods.

Step 01: diagnosis at global scale by using guided wave method

It allows to estimate whether the examined tie-rod is cracked and to select elements requiring further inspections. Data acquisition is performed by using an off-theshelf equipment but signals are post-processed by implementing a code developed in this thesis. The recording of signal takes about 10 minutes per element.

Step 02: diagnosis at intermediate scale by using eddy current testing

It allows the localization of defects on tie-rods selected during step 01. The customized probes designed in this thesis are employed to perform tests. This step takes about 3hours for each strengthening bar.

Step 03: detailed visual inspection

It allows to verify the presence of geometrical variations revealing forged welding or other types of flaws with comparable dimensions. An equipment has been realized to overcome constrictive operating conditions, ensuring firm support and enhanced lighting. This step takes about half an hour.

Step 04: crack characterizations by using ultrasonic phased array

It allows to estimate dimensions of the discontinuities identified in step 02. Although it is an established method, it cannot be employed on historical tie-rods for both economic and timeconsuming reasons, whether it is not used in an integrated strategy restricting inspection area.

Step 05: structural safety evaluation

A traditional approach is not suitable to assess the structural safety of historical metallic tierods. ET results have revealed dominant defects crossing the whole bar section (i.e. forged welding). Although they are often characterized by a good quality, fracture mechanics tests proved that they represent the weakest material cross sections. By knowing the state of stress (from a previous work) and crack dimensions, the actual tie-rod stress intensity factor can be computed. If this value is lower than the material toughness achieved from experimental campaign, crack dimensions cannot be considered critical. If the examined parameter is very close to critical value both natural frequency and acoustic emission monitoring testing might be used to foresee tie-rods behavior in time. As concerns the former the experimental set-up has been chosen and the correlated data transmission procedure has been implemented in LabVIEW environment.

The first three steps of the proposed procedure have been carried out on seven active tierods placed inside the Cathedral. Considering both the tension state and the inspections results, the examined tie-rods have been classified in three different Levels of significance of further investigations: high, medium, low. Three partially open cracks have been identified which clearly correspond to a welding joint. PhD Yearbook | 2017

Briccola Deborah - Supervisor: Prof. Pier Giorgio Malerba

The research deals with the sensitivity of concrete bridge structures to the time-dependent effects due to creep and shrinkage. Several studies carried out in the past have shown that, during their lifetime, sometimes just few years after their completion, reinforced and prestressed concrete bridges can exhibit several shortcomings that can lead to the disappointment of the serviceability requirements. This can indeed limit the performance the structure was conceived for, and represents an undeniable loss of functionality of the infrastructural network. Many of these shortcomings can be related to an improper design practice in which the influence of the time-delayed effects on the static behaviour of such structures are neglected, thus jeopardizing their lifetime performance estimation. This evidence explains why the present study begins with a brief recall of the time-dependent structural analysis in presence of creep and shrinkage. A first

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evaluation is devoted to analyse the sensitivity of some recurrent bridge typologies, in order to outline their intrinsic elastic deformational characteristics. Then attention is paid to recall the basic constitutive laws of viscoelasticity and the different creep prediction models that, to this end, can be adopted. Later, the methods commonly used to reduce the problem to an algebraic form are introduced. These methods lead to the definition of the skeleton of a numerical approach suitable to deal with the target of the research. A computer code for time dependent analysis of reinforced and prestressed concrete structures over time has been developed. Basic applications highlighted how creep and shrinkage phenomena may induce guite different behaviours in such kind of structures. In some cases, they have little influence with respect to the serviceability limit states, while in others they play a significant role for the fulfilment of the required performance also at

the beginning of their service life. Cable-stayed and cantilever type bridges belong to this last category: this is why after a general overview, the research focuses on such type of structures.

Indeed the data related to geometry, material characteristics and tensioning forces, just to quote some, are not deterministic. Hence aim of this work is to explore the effect of the most important uncertainties and their role in affecting the actual behaviour of the structure. Uncertainties associated to this type of problems are dealt with a Monte Carlo approach. According to some design codes, the uncertainties have been treated as random variables described by proper probability density functions. To illustrate the influence of uncertainties on structural deflection a simple cable-stayed structure and a prestressed cantilever beam have been analysed. The selection of significant case studies, type of uncertainties and on field experiences to set up the numerical data for an effective

modelling of such kind of structures has also been addressed. Moreover the sources of uncertainties involved, especially those related to the tensioning

1. Cantilever bridge under construction.



2. Time evolution of the PDF of the tip vertical displacement. (a), (c) Cable-stayed structure, a=30°(a: inclination of the stay). (b), (d) Prestressed cantilever.

forces, but not only, can be treated as fuzzy variables instead as random ones with predefined pdf distributions and problems different from those already considered in which creep and shrinkage can play a significant role might be exploited. The computer code developed for these first evaluations is readily adjustable for further improvements. For instance it is easily adaptable for the analysis of R.C. and prestressed concrete slender columns as the pylons of cable-stayed bridges. Hence a quantification of the influence of time-dependent effects and uncertainties on structural elements, for which not only the serviceability but also the instability limit state is of interest, can be addressed. The works ends collecting the

main structural consequences of the time-dependent behaviour of concrete and suggests design and technological advice to avoid drawbacks which cannot be ruled out by computation only.

MECHANICAL RESPONSE OF REINFORCED DEEP TUNNEL FRONTS IN COHESIVE SOILS: EXPERIMENTAL AND NUMERICAL ANALYSES

Flessati Luca - Supervisor: Prof. Claudio Giulio Di Prisco

In spite of the increasing diffusion of Tunnel Boring Machines, conventional tunnelling is still preferred for economical reasons when tunnels are either short or characterized by a particularly irregular cross section. Moreover, conventional tunnelling is more versatile, permitting adjustments of the excavation technique in case different soils are encountered during the excavation. In conventional tunnelling, the stability and, more in general, the mechanical response of tunnel faces, depending on the soil properties, the system geometry and the excavation technique, are a main concern. In case of particularly difficult conditions, it is common the employment of passive (fibre-glass) nails to support the front. This expensive and time consuming soil improvement technique is, nowadays, designed by employing either empirical approaches or very simplified theoretical formulas. This thesis has the ambition of introducing a new design approach based on the front displacements. To this purpose both numerical and experimental analyses of the mechanical response of unreinforced and reinforced deep tunnel fronts excavated within a homogeneous cohesive soil stratum have been performed. The 3D FEM numerical analyses

campaign under undrained conditions permitted the introduction of a non-dimensional front characteristic curve. independent of the geometry and of the soil properties, allowing to estimate the front displacements without performing any numerical analysis. This curve was also generalized to the case of the reinforced front and was employed to introduce a new reinforcement design approach. The hydro-mechanical coupled system response was also taken into account. The numerical results clearly show that the excavation rate significantly affects the system response. The excavation rate can be employed as a design parameter to control the front displacements. The experimental campaign, consisting in a series of 1g small scale tests, analysed both unreinforced and reinforced deep tunnel fronts. The campaign was mainly focused on the analysis of the effects on the system response of the consolidation process taking place within the soil domain. The results of the experimental tests confirmed the severe influence of time on the system response and a satisfactory agreement with the numerical predictions was obtained.

Hashemydahaj Seyedeh Kiana - Supervisor: Prof. Roberto Paolucci

Co-supervisor: Dr. Chiara Smerzini

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With increasing loss potential of earthquake hazards, especially in highly-populated urbanized areas, there is a need for performing large-scale risk assessments. especially in regions near active faults. One of the key ingredients of seismic risk analysis is the evaluation of the earthquake ground motion. These analyses are usually based on empirical equations typically calibrated on the available worldwide strong motion records. However, in absence of sufficient ground motion records, particularly in near source condition of large magnitude earthquakes, there is a necessity for alternative tools for predicting ground motion and providing a complete picture of their spatial variability. As a matter of fact, with improvements in numerical tools and computational resources, the physics-based numerical simulation of earthquake ground motion emerges as one of promising tool for thispurpose. Stimulated by the motivations

above, the principal intent of this work is to explore various issues regarding characterization of earthquake ground motion by using physics-based numerical simulations. In this regard, the spatial variability of seismic motion in a large urban area has been studied and insights into 3D site effects induced by complex geological structures has been provided.

The main computational tool utilized in this work for simulation of seismic wave propagation is a high performance code named SPEED (http://speed.mox.polimi. it/), based on the Discontinuous Galerkin spectral elements. SPEED is designed to handle the simulation of large- scale seismic wave propagation problems, including the coupled effect of the seismic fault, the propagation path, and localized geological irregularities.

The code has been used particularly for simulation of seismic ground motion in the Thessaloniki broader area which had been selected as a benchmark site in the framework of 2013–2016 STREST FP7 European Collaborative Research Project due to its strategic position for the trade and economy of the region. The availability of detailed geotechnical, geophysical and seismological information allowed the construction of a 3D large-scale model that primarily addresses the simulation of the MW 6.5 June 20th 1978 earthquake, which seriously affected the city. Being validated by available records and the experimental data, the simulated time histories

have been used for investigating the spatial variability of seismic ground motion and the 3D site effects in the Thessaloniki urban area. In addition to that, in order to examine the dependency of the spatial variability of ground motion on the seismic source parameters such as hypocenter location and slip distribution, a total number of 42 ground shaking scenarios has been generated rupturing the same fault.

To improve its applicability for engineering practices, a part of this study has been dedicated to implement some new features in 2D version of SPEED. One of those is a sub-structuring technique for plane wave propagation analyses, called DRM (Domain Reduction Method) in which the analysis of the seismic source and the wave propagation through the earth is separated from the localized structure. The implementation of DRM is SPEED has been validated through different geological configurations and has been used for performing a study on the response of a specific 2D crosssection of the Thessaloniki urban area. In this regard, a systematic comparison has been performed on the performance of 1D, 2D, and 3D numerical approaches for predicting the site response in the Thessaloniki metropolitan area.

It turns out that some specific complex features of seismic response observed in weak motion records, cannot be accurately predicted except with advanced numerical tools based on 3D wave propagation and 3D geological configuration. The final portion of this research

has been devoted to study the spatial distribution of ground motion in near-source condition with respect to the site-to-source distance measurement. For this purpose, the results of numerical simulations in the Thessaloniki area together with other case studies, with different earthquake characteristics, were used. It has been highlighted that for fault normal or reverse faulting earthquakes, the accuracy of empirical ground motion prediction in near-source conditions significantly depends on the proper definition of the distance metric. For this purpose, a new distance metric has been proposed in this work to describe the decrease of the amplitude with distance, and compared with other metrics widely used for thispurpose. **Keywords:** large urban area, physics-based ground motion simulation, Spectral Element Method, seismic source, plane wave, Domain Reduction Method, spatial variability, 3D basin response, distance metric.

MICROMECHANICAL CHARACTERIZATION OF POLYSILICON FILMS: ON-CHIP TESTING, MULTI-UNCERTAINTY QUANTIFICATION AND BAYESIAN INVERSE MODELLING

Mirzazadeh Ramin - Supervisor: Prof. Stefano Mariani

Co-supervisor: Dr. Aldo Ghisi, Prof. Eelco L. Jansen

Due to the ever increasing concerns on efficiency, environmental policies and sustainability in the last years, there is a great demand for novel sensing solutions (e.g. low cost and low energy consumption). These incentives have led to an additional attention to the potentials of the MEMS applications while imposing stricter design constraints, such as smaller dimensions, elevated signal-to-noise ratio and lower energy consumption. To this aim, there is a great demand for novel applications of MEMS devices featuring smaller dimensions and higher reliability. When, due to miniaturization of the MEMS devices, the dimensions of polycrystalline components become comparable to the average grain size or to fabrication inaccuracies, mechanical reliability issues can be reported for the moving parts of inertial MEMS. Not only the overall behavior of the device turns out to be affected by a large scattering, but also the sensitivity to imperfections is increased. In this work, a comprehensive study of these reliability issues at the micro scale is provided. To this aim, a set of MEMS test devices (see e.g. Figure 1)

is fabricated, and the results are analyzed by means of both analytical and numerical approaches. An experimental campaign is designed consisting of several on-chip test devices realized by means of common microfabrication techniques. The main goal of these devices is to investigate the apparent mechanical properties of a polysilicon micro beam as the fundamental structural component of MEMS applications. The micro beams feature a width of 2 µm which accommodates, in average, only 3-4 silicon grains. Actuation and sensing are realized using standard electrostatic methods, similar to those in the commercial applications. The electromechanical responses of several devices have been recorded showing relatively large scatterings, despite their nominally identical specifications. Such observation can be due to the differences in i) the material properties of the beams due to their microstructure (polysilicon morphology), or ii) in the geometrical uncertainties originated from fabrication inaccuracies. In order to investigate the effects of the variations of material properties, Monte Carlo

simulations are employed, taking into account the polysilicon random morphology. The results of these simulations demonstrate some degree of dependency of the electromechanical response on the polysilicon film properties, but they show also that the large scatterings cannot be explained on material properties ground only; the fabrication inaccuracies have a key role in the experimentally observed scatterings. Taking into account both material properties variations and fabrication inaccuracies, parametric analytical/numerical models are henceforth provided for the test devices. Dealing with the unknown parameters of the models as deterministic or stochastic variables, several parameter estimation techniques are adopted in this work, including Levenberg Marguardt, genetic algorithm, particle filtering and Transitional Markov Chain Monte Carlo (TMCMC). Based on the experimental measurements, the unknown parameters are successfully estimated for each specimen. Finally, a non-intrusive computation reduction method coupled with the TMCMC is used for Bayesian inverse modelling

of the uncertainty quantification for this specific test device. The proposed computation reduction method is a synergy between the proper orthogonal decomposition (POD) and kriging metamodelling. This method constructs a reduced model of a finite element one at a very low computational effort and high accuracy level, while the TMCMC is a stochastic method that takes the measurements error into account and provides, not the value of the unknown parameter, but its probability distribution. The successful applicability of this method is shown for the actual measurements of the MEMS test device.



1. (a) Device geometry with (b) detail of the beam region and (c) in proximity of the lateral stator.

elements during a seismic event

Between the multiple choice

among the hardware today

system (Figure 1) has been

available, the sliding pendulum

proposed as a desirable solution.

The seismic performance of the

sliding pendulum depends on

suggests the use of base isolation.

Tavecchio Charlotte - Supervisor: Prof. Stefano Capolongo

Co-Supervisor: Prof. Virginio Quaglini

For sensitive structures located in high seismicity regions, whose integrity during earthquakes is of vital importance for the management of the post-event emergency, the Italian building code requires full operationality during and after a seismic attack. Therefore healthcare structures and emergency hospital departments need to be designed



1. Sliding Pendulum System.

in order to remain fully operational for emergency response in the eventuality of moderate to severe earthquake ground motions. The need of preserving full operation without any damages to both structural and non structural analysis of the advantages and disadvantages of state of art materials for the sliding surfaces points to the need of novel materials with enhanced properties in terms of thermal stability of the coefficient of friction, in order to cope with the huge temperatures developed at the sliding surface during severe seismic loading.

Both Polytetrafluoroethylene (PTFE) and Ultra High Molecular Weight PolyEthylene (UHMWPE), that represent the state of the art materials have drawbacks linked to the decrease of compressive strength at high temperatures generated by friction forces. A new material, consisting of an enhanced polyamide, has been proposed and its suitability for use in seismic isolators assessed by means of a custom procedure, aiming at characterizing the dependency of the coefficient of friction on operational parameters like pressure, velocity and cumulative cycling distance in the typical range of severe seismic events.

A series of tests have been conducted on small scale sliding bearings installed on a custom testing machine (Figure 2) obtaining the measurements of static and dynamic friction coefficients for bearing pressure ranging from 15 to 60 MPa and for sliding velocity between 1 mm/s and 200 mm/s. Duration of loading has been tested up to 300 cycles corresponding of a total sliding path of 10 m, well beyond normally seismic sliding paths.



2. a) Specimen geometry b) Schematic drawing of the test model of flat bearingof flat bearing

The results of these experiments are then used to establish two different friction models for enhanced polyamide sliding bearings.

The first mathematical law is formulated starting from the most accredited model for PTFE, with adaptation to for the material under investigation, and then further modified to account for friction degradation due to thermal heating generated during a seismic event. Furthermore a simplified method to be used in linear analyses, with Coulomb friction coefficient, is eventually proposed and justified. The second mathematical law is a completely new refined friction model accounting for velocity, pressure, heating due to cycling and wear dependence. Finally sliding pendulum isolators with the characterized sliding material are used in numerical analyses of San Giovanni Rotondo

hospital (Figure 3) and their performance is evaluated based on the absence of damage to non structural elements of the isolated building.

The hospital complex with the implementation of the isolation system with enhanced sliding material is capable to withstand the medical emergency for (SLV) Life-Safety Limit state within the threshold of minor damages. The protection of strategic and high sensitive buildings from earthquake damage is vitally important. With relevance to developed countries, seismic risk involves particularly the southern areas of Europe, including Italy, the west coast of North and South America, China, Japan and New Zealand. The research provides new

chances for the development of more efficient and more reliable devices for seismic isolation, in particular the impact can be



3. Rendering of SGR hospital complex for preliminary design.

summarized as follow:

- The use of high performance sliding materials with properties tailored for seismic isolation systems will increase the safety of civil engineering works against seismic actions;
- The development of sliding materials that overcome the limits of current materials will allow the design of more performing devices, with technical and economical benefits;
- 3. The optimization of the mathematical model accounting for degradation effect of friction characteristics due to repetition of cycles and consequent temperature rise is suitable for implementation in generalized structural analysis codes and provides an important design tool for realistic assessment of the seismic response of structures equipped with friction-based isolators.

MEMS SENSORS FOR THE MEASUREMENT OF ANGULAR VELOCITY: MECHANICAL AND STRUCTURAL ISSUES

Zega Valentina - Supervisor: Prof. Alberto Corigliano

Co-supervisor: Prof. Claudia Comi, Prof. David A. Horsley

Micro Electro Mechanical Systems (MEMS) technology has revolutionized inertial sensors such as accelerometers and gyroscopes. Since the first demonstration of a micromachined gyroscope by the Draper Laboratory in 1991, a number of different micromachined gyroscope designs fabricated with different technologies have been reported. MEMS gyroscopes measure the external angular rate by exploiting different physical phenomena among which the most popular one, up to now, is the Coriolis effect. Moreover, they are expected to lead to reliable, robust and high performance angularrate sensors with low production costs and high yields, fitting into or enabling many applications in the aerospace/defense, automotive and consumer electronics market. The main purpose of the thesis is to discuss some of the critical aspects of the MEMS Coriolis based gyroscopes and give a possible solution to them from the mechanical and structural point of view. In particular the robustness against fabrication imperfections and environmental fluctuations is a key issue during the design process of a MEMS gyroscope in order to guarantee good performances of the devices.

For similar reasons, the designer of MEMS gyroscopes has, also, to deal with nonlinearities that arise because of the reduced dimensions of the mechanical components or for the actuation/ detection schemes. Nonlinear phenomena must be, then, studied in deep with the purpose to understand how they can improve or compromise the functioning of the gyroscopes. Finally, the design of smart springs and mechanisms is of fundamental importance when smaller and smaller devices are required from the market. A new kind of MEMS gyroscopes, the frequency modulated (FM) gyroscopes, is, then, proposed to fulfill the need of robustness against fabrication imperfections and environmental fluctuations: in fact, it promises to improve long term scale factor stability and long term bias stability and to lower the power consumption. The design of FM yaw, pitch/ roll and triaxial gyroscopes is proposed in the first part of the thesis together with an

explanation, from the theoretical

point of view, of the new working

In the second part of the thesis,

two nonlinear dynamic models

are, instead, studied from

the analytical, numerical and

experimental point of view,

principle.

to explain the self-induced parametric amplification that significantly improves the performance of disk resonator gyroscopes and the dynamic pull-in that can compromise the behavior of resonant devices such as accelerometers or gyroscopes. Finally, to fulfill the need of smart auxiliary springs that guarantee the motion of the masses of MEMS gvroscopes without breaking the main constraints in terms of footprint, performance and fabrication process, some new motion conversion mechanisms are proposed. Auxetic structures have been, for this reason, exploited and properly optimized.