Chair:
Prof. Roberto Paolucci

DOCTORAL PROGRAM IN STRUCTURAL SEISMIC AND GEOTECHNICAL ENGINEERING

Objectives of the Doctoral Program

Structural, Seismic and Geotechnical Engineering - SSGE consists of 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 micro-systems), (c) soils, and (d) environment-construction interaction. Being deeply-rooted in Civil Engineering, which is – by its own nature – highly inter-disciplinary, SSGE focuses also on the environmental actions, either external (like earthquake, vibrations, irradiation, wind and fire) or ensuing from soil-structure interaction (like those caused by retained-earth thrust, landslides and water-table fluctuations). Because of their generality in materials and structural modeling, the methods developed within the domain of SSGE are very advantageous also in other technical-scientific domains, whenever understanding and controlling the mechanical aspects are necessary to guarantee both design reliability and structural safety, serviceability and durability. Many are the examples of the issues typical of 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 quote many issues that are in common with several branches of Industrial Engineering. Within this context, the primary objective of this Graduate School is to favor the advancement of the knowledge, with reference to: (a) innovation in materials and structures; (b) building safety under highly-variable actions; (c) soil and surface/buried structure stability; and (d) biomechanics, that is a key aspect of industrial bio-engineering. This objective is pursued by giving the PhD Candidates an advanced, research-oriented formation, based on the pivotal role of Structural Engineering and on the multi-disciplinary nature of Seismic, Geotechnical and Bio-Mechanical Engineering.

Contents of the Doctoral Program

The Candidates are offered several advanced courses on a variety of topics concerning materials and structural mechanics, computational and experimental methods, and structural reliability, the focus being always on both basic issues and engineering applications. As a consequence, great attention is given to many fundamental topics still highly-debated within the scientific community, and to many application-oriented topics, that are of direct interest for the public and private industry, for the designers and for the institutions dealing with structural safety and reliability, and with the environmental impact of the structures.
The study plan includes courses and seminars given by scientists, experts and researchers active either in the Politecnico or in other Italian and foreign universities, research institutions and high-tech firms. The study plan is divided into 4 phases:

1. Propaedeutic formation, based on courses borrowed among the MS courses ("Laurea Magistrale"), with the objective of giving a common scientific basis to the PhD Candidates coming from different schools.
2. Basic, research-oriented formation consisting of 5-credit courses to be taken by the Candidates, to complete and enrich their scientific formation. These courses are focused on the most relevant topics debated within the scientific community, in the domains of materials and structural mechanics, structural dynamics and seismic engineering, soil mechanics and research management.
3. Specialized, research-oriented formation based on a variety of opportunities offered to the Candidates: (a) short courses, and (b) series of seminars given by either internal or external faculty members, as well as by researchers from the industry, from the Society of the Engineers and from public institutions; and (c) short courses offered by well-known scientific institutions, like CISM - Int. Center for Mechanical Sciences (Udine, Italy), IUTAM - Int. Union of Theoretical and Applied Mechanics (Summer Schools in different places in Europe), Rose School (Pavia, Italy) and JCR – Joint Research Center (Ispra - Varese, Italy). The Candidates are also suggested to attend the short courses organized by other Doctoral Schools, at the Politecnico or at nearby universities (Politecnico di Torino, Universities of Genoa and Brescia, ...).
4. PhD Dissertation, whose preparation (in English) is a pre-requisite for being admitted to the final examination. The dissertation should contain original results concerning relevant and actual engineering problems, with reference to basic topics or to applications and technology. The preparation of the dissertation consists of different phases, whose results are presented by each Candidate at the end of the 1^{st}, 2^{nd} and 3^{rd} year, in specific workshops, open not only to the Faculty and to the PhD Candidates, but also to the members of the Advisory Board and to all interested scholars.

To earn credits and to start or to refine their dissertation, the Candidates are highly suggested to spend a period abroad, in one of the universities or research centers that have systematic scientific relations with the Politecnico di Milano. At the same time, the PhD School favors the visit of foreign scholars, to give short courses in Milan. In this way, the Candidates are offered a number of opportunities to interact with the international community.

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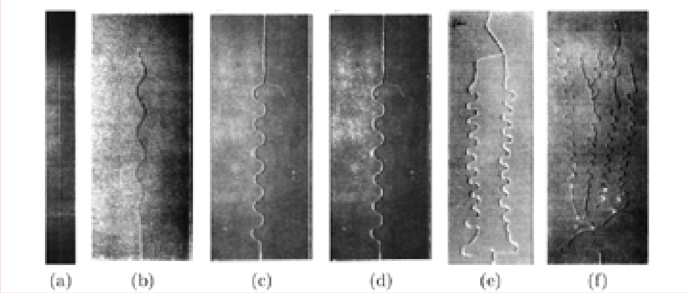
FINITE ELEMENT MODELING OF THERMAL INDUCED FRACTURE PROPAGATION IN BRITTLE MATERIALS

Giovanna Bucci

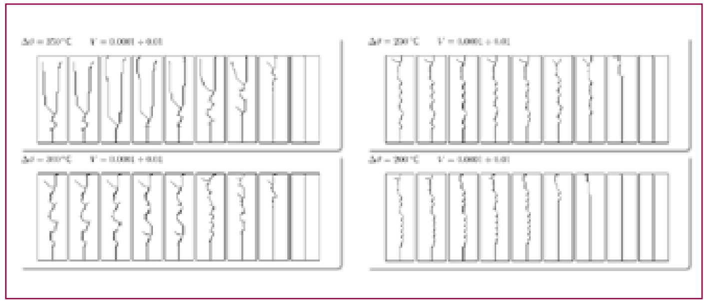
The direction of propagation of a crack and in particular the stability of straight propagation are fundamental problems of fracture mechanics not yet fully understood. One of the obstacles to this understanding is represented by the difficulty to perform well-controlled experiments.
Multiple simple tests ([Yuse&Sano 1993], [Ronsin et al. 1995]) have showed that a crack traveling in a thin glass plate with a thermal stress field undergoes a reproducible sequence of instabilities. Fracture propagation due to sudden but controlled cooling shows drastic morphological changes depending on the values of the experimental parameters. The patterns observed can be grouped in four categories (see Fig. 1): i) no propagation, ii) straight propagation, iii) crack oscillating with different possible amplitudes, iv) branching patterns of various complexity.



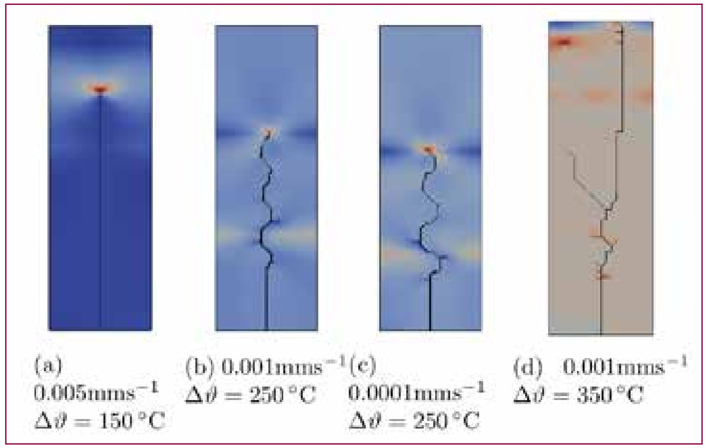
1. Crack patterns recorded in [Yuse&Sano 1993, 1997]: a) straightpropagation; b) sinusoidal pattern; c) oscillating propagation in a large plate;d)oscillating crack pattern describing semicircles; e) two-branch crack withoscillation; f) pattern with multiple branches.

The present work aims to derive the instability of the straight crack propagation as an outcome of the numerical analysis, not requiring the formulation of an analytical kinking criterion and severe approximation of the problem.

The thermo-mechanical problem is solved by a finite element code, in a two-dimensional approximation of the spatial set and imposing a quasi-static evolving temperature profile. The fracture propagation in brittle materials and in quasi-static conditions is modeled with cohesive finite elements, in order to predict the crack pattern depending on the stress concentration at the crack tip. The main set of numerical experiments has been performed by keeping constant material and geometry of the sample and varying the temperature gap Δθ between hot and cold region form 150°C to 300°C and the immersion speed V from 0.0001mm/s to 0.01mm/s, in order to investigate the dependence of the results on these two parameters.
From the resulting fracture patterns (see Fig. 2) it is possible to deduce that the non-linear kinematics description of the system and the cohesive elements regulating the failure at the element interfaces have been able to capture oscillating and branched patterns. The computational cost for a large number of analysis has imposed a limit on the mesh size; despite of that the crack grows trying to respect the symmetry respect to the vertical central axis, while following non-trivial paths. Confirming experimental observation, for a fixed velocity, the wave length in the oscillation increase with the temperature gap. For Δθ = 350°C the fracture patters are characterized by higher instability, most of them have an initial oscillating path. The fracture splits then into two branches, which propagate in almost straight and symmetrical directions. For Δθ = 150°C, Δθ = 175°C the crack grows straight. The transition threshold is localized in the interval Δθ = 175 – 200°C. the two relevant



2. Fracture patterns resulting from numerical tests imposing Δθ and V varying in the range 200 – 350°C and 0.0001 – 0.01mm/s respectively. The immersion velocity grows from left to right in each of the four sets of images.



3. Fracture patterns resulting from numerical tests performed with arefined mesh.

geometric dimensions are the plate length and the plate width.

The strain energy stored into the material, in function of the severity of the thermal gradient and of the largeness of the plate, influences the fracture propagation as driving force. The energy dissipated in the damage process is proportional to the crack path length, so that wavy patterns and multiple branching allow the system to release higher quantities of energy respect to the straight fracture.

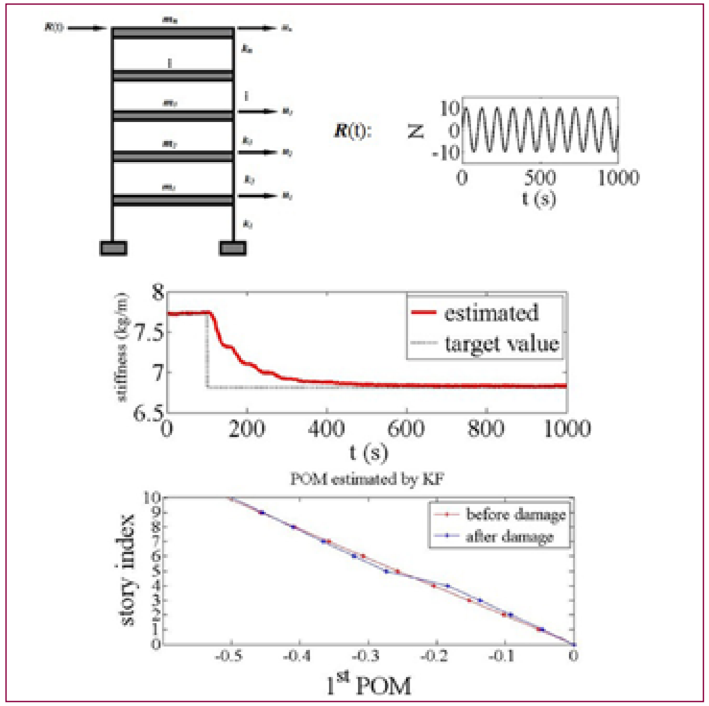
The theory of bifurcation problems offers a framework to understand the peculiar instability associated with a quasi-static crack propagation.

The phenomena experimentally observed can be interpreted as an Hopf bifurcation of the solution of the equation of motion of the crack tip. The Hopf bifurcation refers to the development of periodic orbits ("self-oscillations") from a stable fixed point, as a parameter crosses a critical value. The drastic change in the crack morphology according to the experimental parameters is a clear manifestation of an instability phenomenon. Furthermore the arising of periodic stable solutions is evident in the oscillating patterns characterized by wavelength and amplitude depending on the test settings. It is possible to identify another threshold, which represents the limit of stability for the oscillating crack pattern and the appearance of branching. It delimits the transient from periodically stable to unstable solutions.

DUAL ESTIMATION AND REDUCED ORDER MODELLING OF DAMAGING STRUCTURES

Saeed Eftekhar

The objective of the work presented in this thesis is to develop damage identification techniques for vibration based non-destructive damage identification of the structures. The emphasis is on the development of fast and robust recursive damage detection algorithms, in order to facilitate the task of online real-time continuous monitoring of civil structures, like e.g. residential buildings, bridges etc.. To this end, four Bayesian filters, namely the extended Kalman filter (EKF), the sigma-point Kalman filter (SPKF), the particle filter (PF) and a hybrid extended Kalman particle filter (EK-PF) are adopted to identify the structural system. To avoid shadowing effects of the structural system, performance of the filters is benchmarked by dual estimation of state and parameters of a single degrees-of-freedom structure featuring nonlinear behaviours: an exponential softening and a bilinear (linear-softening, linear plastic and linear hardening) constitutive laws are studied. It will be seen that the EK-PF outperforms all the other filters studied here. It has to be underlined that, though Bayesian filters have been extensively studied in the automatic control field, their use in structural engineering is still to be investigated. The existing literature offers applications of EKF and SPKF and PF to simplified, low dimensional models; however, to the best of our knowledge, the use of EK-PF has never been reported when dealing with a structural engineering problem. After the performance of the filters are benchmarked when dealing with a single degree-of-freedom system, multi degrees-of-freedom shear building structures are dealt with. In this regard EKF, for its computational efficiency and EK-PF, for its excellent performance dealing with single degree-of-freedom systems, are adopted. It will be shown that performance of EKF and EK-PF is similar when dealing with a two degrees-of-freedom system; however, moving to three and four degrees-of-freedom structures, EK-PF outperforms the EKF in terms of the bias in the estimation. It is realized that, as the number of the degrees-of-freedom increase, the adopted methods lose their accuracy in system identification and therefore, in damage detection. This problem is raised due to the high dimension of the parameter space, i.e. by so-called curse of dimensionality. To cope with this issue, here we make recourse to reduced order modelling of the systems. As for the model order reduction technique, a method based on the proper orthogonal decomposition (POD) is adopted. Such method makes use of POD to define a subspace in which main dynamic evolution of the system takes place; the vectors that span the POD subspace are called proper orthogonal modes (POMs). Once such a subspace is obtained, a projection method onto the POD subspace is used to reduce the order of the set of governing equations of the system, and then speed-up the calculations. Besides the speeding up the calculations, another striking property of the so-called POMs is that they are sensitive to changes in the system parameters, this property, is here exploited to identify the damage in the structure.
The main contribution of the work presented in this thesis is the development of a recursive stochastic algorithm, by a synergy of dual estimation concept, POD-based order reduction and subspace update. The proposed methodology takes advantage of Bayesian filters (e.g. EKF and EK-PF) for dual estimation of state and parameters of a reduced order model of a time-varying system. Within each time iteration, a Kalman filter is used to update the subspace spanned by the POMs of the structure. The efficiency and effectiveness of the algorithm is verified via pseudo-experimental tests, carried out on a ten-storey shear building. It is shown that the procedure successfully identifies the state, the model parameters (i.e. the components of the reduced stiffness matrix of the structure) and relevant POMs of the reduced model. Unbiased estimates furnished by the algorithm permits the health monitoring of the structure.



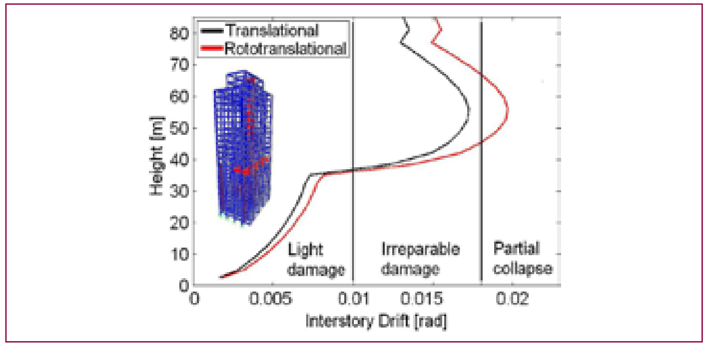
1. Schematic view of a shear type of the building which is excited by a harmonic force at the top floor: time history of estimation of the reduced stiffness and the proper orthogonal mode of a single degrees of freedom reduced model are shown to be estimated un-biasedly

NEAR-FIELD EARTHQUAKE GROUND MOTION ROTATIONS AND RELEVANCE ON CIVIL ENGINEERING STRUCTURES

Roberto Guidotti

Introduction

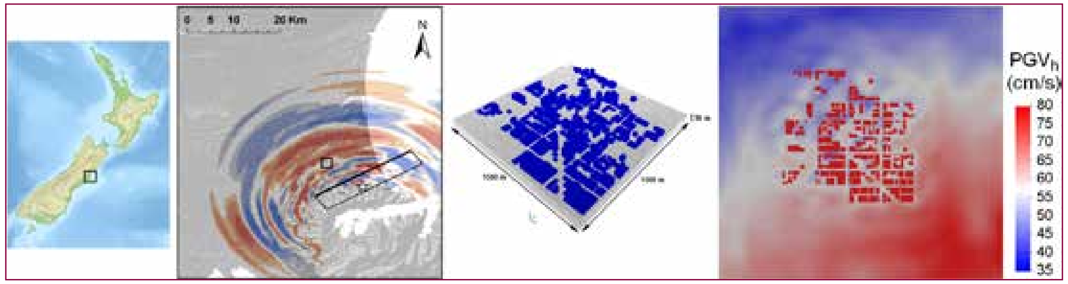
The growing interest in the study of rotational ground motions induced by earthquakes, explosions, and ambient vibrations has led in recent years to the development of an emerging field of inquiry, referred to as *Rotational Seismology*. The main idea of the rotational seismology is that for a complete and proper characterization of strong ground motions, measurements should be no longer limited to only the three components of translational motion, but should simultaneously include the three components of rotational motion, especially in the near field of an earthquake, where soil response influences ground motions in a complex way. Furthermore, accelerations recorded by translational sensors could themselves be affected by rotations and collecting translational and rotational information together can yield a substantial improvement in studies of velocity heterogeneity, source complexity, and media nonlinearity in strong ground motions. From a civil engineering perspective, the relevance for structures is still under debate by the scientific community and the notion that the rotational component of strong motion could contribute significantly to the overall structural response has only recently been recognized, driven by a growing interest in performance-based design and structural health monitoring. In particular, in buildings, considering a vertical motion differing from point to point, the wave passage effect provides an overall rotation of the base of the structure, with an overturning motion, involving horizontal displacement of the centre of mass. To disregard this effect could result in underestimated interstory drift and, consequently, higher levels of damage than expected [Fig. 1]. Nevertheless, studies of recorded rotational strong ground motion are limited to a few examples and, consequently, the knowledge of the rotational wave field is still insufficient.



1. Interstory drift along the height of the Grand Chancellor Hotel, considering a pure translational and a roto-translational input.

Methodology

The goal of this work is to make a contribution to the study of rotational ground motion in near-field region, referring to a realistic earthquake scenario, as with the M_W 6.3 Christchurch, New Zealand, earthquake of 22 February 2011. The exceptionally high vertical acceleration recorded together with the widespread liquefaction, suggests that rotational motions could have played a significant role in the damage of the area, and especially in the Central Business District (CBD) of the city, characterized by a dense urban setting with closely spaced high rise buildings. Aiming to further understanding of the rotational wave field and its relation with the translational wave field, rotational ground motions are evaluated: i) semi-empirically, starting from measured translational records in closely-spaced arrays of stations, relying on the mathematical relation between the cross power spectrum and the power spectrum of rotation; and ii) numerically, considering the prediction of the variability of strong ground motion (translational and rotational) in near-fault conditions obtained through 3D models of the Canterbury Plains, testing their reliability by exploiting the availability of an unprecedented dataset of recorded near-fault strong ground motion.



2. Modelled multi-scale wave propagation problem: from the regional scale (Canterbury Plains) up to the local scale (CBD of Christchurch).

Discussion

The relevance of the rotational strong ground motions is evaluated for a series of civil engineering structures: i) buried pipeline and lifeline networks; ii) tall wind towers; iii) high rise buildings; and iv) pounding-prone compounds of buildings. In order to define a more accurate relationship between rotational and translational ground motion, more measured data are necessary, however the methods and the procedures adopted in this work, together with the main results obtained, constitute a basis for future developments and further studies. In particular, the innovative non-conforming meshing approach, introduced in the modelling phase of the Christchurch CBD, allowing the contact between elements of different sizes in different sub-domains, lays the basis for a noticeable development of the numerical simulations. Reducing the overall number of elements, it lightens the computational burden of the problem and allows the study of the typically multi-scale wave propagation problem, from far-field to near-field regions, up to the evaluation of local Site-City interaction effect [Fig. 2]. That, in combination with the wave passage effect, could help to explain the observed variability of damage in apparently homogeneous areas.

Notwithstanding their low probability, "Christchurch-like" seismic events are not isolated cases. They constitute an important element in overall risk management approach, proving that, even if earthquake engineering and all the related research fields tackle efficiently the challenge of earthquake catastrophes, nonetheless the fragility of modern society is still quite high. How to work toward building an earthquake resilient society seems to be the next defiance. Furthermore, the major events of the last years dramatically reminded us that the reliable assessment of earthquake-induced damages and losses is a problem of paramount importance, leading us to further reflect on the way risk is presently addressed and about the role of numerical simulations in seismic hazard assessment studies.

MODELING OF DEGRADATION INDUCED BY ALKALI-SILICA REACTION IN CONCRETE STRUCTURES

Rossella Pignatelli

The alkali-silica reaction (ASR) is a slow reaction occurring in concrete composed by certain type of aggregates containing amorphous silica and cement paste containing alkali. Commonly the reaction starts in the interfacial zones between the aggregates and the cement paste and forms an amorphous alkali-calcium-silica gel. In the presence of water the gel swells and causes expansion of concrete. After filling the initial concrete porosity, the gel starts exerting a pressure on the concrete matrix which can reach the value of the tensile strength of concrete, causing micro-cracking and, with time, macro-fissures.
The structural consequences can be very serious, as many dams and bridges built some decades ago demonstrate. The concrete cracking causes a decrease in the mechanical properties of the material and the presence of fissures makes the entrance of further aggressive agents easier. Indeed the presence of cracks not only permits water to enter in the structures with the formation of further gel, but also increases the possibility of other chemical and physical attacks.
Many experimental campaigns have been performed to assess the influence of environmental factors, such as temperature and humidity conditions, on the ASR development and several mathematical models have been proposed to simulate the mechanical effects of ASR, following both microscopic and phenomenological approaches.

The main objective of the present work is to develop a phenomenological model to be used in large scale structural analysis in the presence of varying temperature and humidity conditions, accounting for the degradation induced by the ASR and the long term behavior of concrete.
The electrical double-layer theory has been used to interpret the expansive behavior of the alkali-silica gel and to estimate the pressure that the gel exerts on the concrete skeleton surrounding the reactive site, starting from the data on the surface charge density measured on gel specimens from Furnas dam (Brazil).
Two different models are proposed to describe the consequences of the gel swelling, both in the framework of a general poromechanical approach: (i) a three-phase elasto-damage model for the description of the simultaneous influence of temperature and humidity on the alkali-silica reaction and of its structural consequences; (ii) a model founded on a more realistic microscopic scheme and based on the coupling of two different damage variables, the chemical damage and the mechanical damage.

The first model is the extension of existing models, intended to catch the effects induced by the alkali-silica reaction (ASR) when simultaneous gradients of temperature and humidity occur, due to changes in the boundary conditions. The quantity of water present in the structure is taken into account through the degree of saturation and the heat and moisture gradients are computed through two independent diffusion analyses. In the framework of the theory of multi-phase porous materials, concrete is conceived as the superposition of three homogenized phases: the concrete skeleton, the gel produced by the chemical reaction and the water. The ASR kinetic is described by using an intrinsic time, expressed as a function of the latency time and the characteristic time, depending on both temperature and degree of saturation. A law describing the simultaneous effect of temperature and humidity on the kinetic of the reaction is proposed; it is based on the combination of the Arrhenius law for temperature with experimental data for moisture. Also the influence of moisture on the final expansion is taken into account. The modeling of the mechanical behavior of the concrete skeleton is based on the damage theory, in order to assess the decrease of stiffness due to cracking caused by ASR. The model considers also the effects of long term shrinkage and creep effects.
A two-phase formulation is also introduced as a particular case of the general three-phase formulation. This simplified approach is suggested by the evidence that, in concrete affected by ASR, the swelling of the alkali-silica gel in the presence of water is the overriding phenomenon, especially for the high humidity environmental conditions of the majority of the reactive concrete structures. Moreover the two-phase approach needs less material coefficients then the three-phase model. This is a relevant point because the experimental information available in literature does not permit to calibrate the parameters necessary for a poro-mechanics three-phase approach accurately enough, especially those regarding the interaction between gel and water filling the concrete porosity.
Both the three-phase and two-phase models have been validated with the experimental results on reactive concrete cylindrical specimens. Then the model has been employed for the structural finite element analysis of reactive plain and reinforced beams and of a concrete gravity dam affected by ASR. To compute the degradation effects of ASR on concrete structures when temperature and moisture gradients vary in time, the mechanical analysis is preceded by the heat diffusion analysis, governed by Fourier law, and by the liquid moisture diffusion analysis. It is shown that the ASR deterioration is driven by the heat diffusion in massive structures while it is governed by both the heat and the moisture diffusion in slender structures, depending on the applied boundary conditions.

The second model starts from both the analysis of X-ray images representing the damage induced by ASR and the values of the gel pressure obtained through the double-layer and attempts to connect the phenomenological approach of poromechanics with experimental information at the micro-scale.
The model is based on the coupling of two isotropic damage internal variables, the chemical damage and the mechanical damage. This idea comes from the observation that in the poro-mechanics model proposed in the literature, including the three-phase model here proposed, good predictions of the expansion can only be obtained by assuming values for the gel pressure one order of magnitude higher then the values measured by mechanical tests or computed using the surface chemistry theories. This unrealistic behavior is due to the fact that in the framework of poro-mechanics all phases are homogenized and, hence, the deterioration of one phase, e.g. the concrete skeleton, is smeared homogeneously. A different behavior is observed in reactive concrete structures: there is a severe damage in the neighborhood of the reactive sites while the overall mechanical properties reduction is limited. To obtain a more realistic modeling of ASR effects, a reference volume element composed by a pore filled with expanding gel and surrounded by concrete matrix is considered. The chemical damage, depending on the reaction extent, is restricted to a small portion of matrix surrounding the pore, harshly damaged by the gel pressure. The chemical damage and the extension of the damaged part are obtained by an identification procedure based on the Young's modulus reduction of reactive samples and the values of pressure computed using the diffuse double-layer theory, both referred to free-expansion. The mechanical damage depends on the overall stress, affects both the concrete skeleton and the gel and allows to model the homogeneously distributed degradation due to external loads. The chemical damage model is validated with the experimental results on reactive specimens, the coupling between chemical damage and mechanical damage is validated by finite-element simulations of compression tests and three point bending tests on reactive concrete specimens.

LIFETIME PROBABILISTIC SEISMIC ASSESSMENT OF MULTISTORY PRECAST BUILDINGS

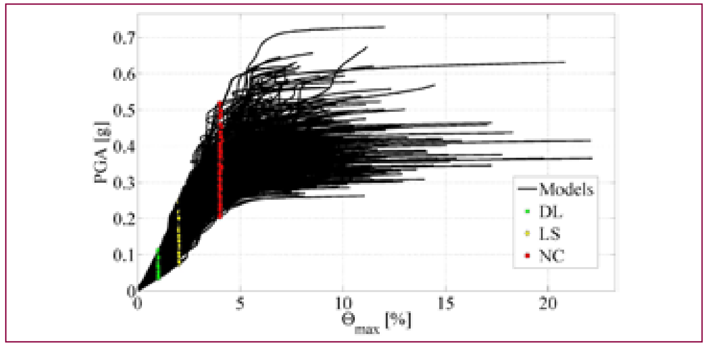
Andrea Titi

Introduction

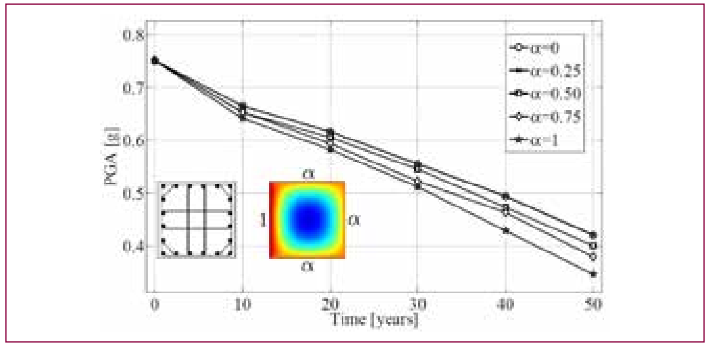
Evaluation of seismic performance of structures during lifetime is an emerging issue in the research community. A key aspect concerns the possibility to include in the seismic assessment the effects of environmental hazards, because current seismic codes are time-invariant and do not take into account such problem. Actually, considering the lifetime of a generic structure, the energy dissipating collapse mode may vary due to a reduction of both strength and ductility of the sections where plastic hinges are expected to occur during an earthquake. Such an interaction could finally bring to undesired failure mechanisms. Regarding environmental hazards, this investigation focuses on the role of a chloride attack, evaluating the loss of mechanical properties of the structural elements. Among different structures, precast buildings are particularly subjected to the effect of corrosion because most of structural members can be directly exposed to the atmosphere. In such conditions, the diffusive attack from external aggressive agents, like sulphates and chlorides, can take place and lead to a deterioration of concrete and steel. With respect to this problem, in recent years different mitigation strategies emerged, with the purpose to extend the lifetime of reinforced concrete. In particular, new advanced materials have been proposed and the present thesis focuses on the use of the so called Engineered Cementitious Composite (ECC) in place of normal concrete which allows, by an appropriate mix design and adding a minimum quantity of polimeric fibers, the formation of multiple narrow cracking in structural elements. This leads to a localized damage and a more uniform distribution of energy dissipation.
Finally, considering that all the phenomena involved have an inherent variability, the rational approach to take into account their randomness is based on a probabilistic assessment. In particular, if random variables are included, the numerical process with repeated simulations can be based on MonteCarlo sampling technique. However, due to his computational cost, advanced tools are needed, and a stratified sampling called Latin Hypercube is therefore implemented, since such technique requires a relative small number of simulations to have reliable information on the performance of structural systems.

Methodology

The present study focuses on two main directions. From one side the purpose is to contribute to develop a reliable framework to perform a structural assessment of multistory RC frames subjected to chloride attack during the whole lifetime, in order to understand how environmental hazards can modify the overall seismic performance. A set of six low-rise precast frames, designed according to a capacity criteria, is considered, changing the size of structural members in order to cover a sufficiently wide range of the structural behavior. Nonlinear seismic analyses (see e.g. Figure 1) are performed during lifetime in order to check the capacity of the structures at different times, considering different limit states, from limited damage up to collapse. Structural assessment is carried out by using a calibrated element model capable to simulate the flexural response of RC elements. A rigorous study on diffusion process of aggressive agents in concrete sections is done, implementing a code for the numerical simulation of such mechanism in one-dimensional and bi-dimensional domains. Finally, the code is used to simulate the diffusion process of chlorides and the subsequent damage in the cross-sections of structural members in order to evaluate how the deterioration of steel bars influences the reduction of strength and ductility of the systems studied, see Figure 2. From the other side, a



1. Seismic capacity and limit states by probabilistic incremental dynamic analysis (IDA)



2. Time evolution of seismic capacity (PGA 5% fractile) of a reinforced concrete frame for different exposure conditions

risk mitigation strategy is investigated, replacing in the dissipative zones of the structures standard concrete with another cementitious composite, namely Engineered Cementitious Composite (ECC). The name “Engineered” depends on a proper tailoring of the micromechanics of the material, suitable to match different classes of target applications.
In this study ECC is applied in order to improve the seismic behavior of precast structures and their durability during lifetime. A moment-rotation law is proposed and calibrated considering the peculiarity of this composite, repeating nonlinear analyses and comparing the overall seismic response during time of both concrete and ECC precast frames.

Conclusions

The investigation underlined the significant influence of environmental hazard on the seismic performance of precast structures during their lifetime, quantifying his role in an effective way using the tools developed. In fact, one of the most relevant contributions of the present investigation is the possibility to show and evaluate how same structures, placing at sites with the same seismic hazard, can have a different seismic reliability depending on the environmental conditions. Such results should lead to improve the current seismic design criteria included in design codes and recommendations to properly take into account the potential coupling among seismic and environmental hazard.