Abstract of Research Project
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RESEARCH PROJECT (max 3 pages):

A NEW APPROACH FOR STRUCTURAL ASSESSMENT BASED ON COMPUTATIONAL COLLAPSE ANALYSIS AND SATELLITE REMOTE SENSING MONITORING

Introduction and state of the art

Progressive collapse, which means the process by which an initial local damage spreads throughout the structure and leads to its partial or total collapse, represents one of the most fearful events for any building.

Studies in this field are getting a growing interest in the last years, due to the recent dramatic failures of important infrastructures (e.g. the Morandi Bridge in Genoa and the Albiano-Magra Bridge) and structures (cases of monumental buildings collapse after earthquakes). Another interesting aspect concerns the possibility of evaluating the residual resistance of damaged buildings with respect to both slow and impulsive events, to understand if interventions are needed in order to avoid their collapse.

The starting point for evaluation and prevention of progressive collapse is an effective numerical analysis, able to simulate the behavior of the structure considering the dynamics of damaged buildings (e.g. equilibrium during and after shock in a seismic sequence or load redistribution after the removal of one or more structural elements).

The progressive collapse of a structure is a complex phenomenon involving nonlinear material behaviour, large deformation and sometimes impacts/collisions, so understanding the mechansms involved and predicticting, if possible, its occurrence in existing buildings is a stimulating challenge for the reaserch.

Many advanced computational techniques were developed in the last years for structural and collapse analysis, which are based on different modeling methods.

The most common used is the Finite Element Method (FEM), which often makes use of elasto-plastic constitutive models including damage parameters for the description of non-linear dynamic behaviour of a structure [1]. Other techniques are base on the Discrete Element Method (DEM), in which the structures are modeled through the assembly of rigid blocks interacting between them at the interface through specific constitutive laws [2]. Recently, another approach has been developed for the description of the structural demolition problem, which is called Applied Element Method (AEM) and tries to combine the advantages of FEM, which gives information regarding local stress/strain fields, and of DEM, requiring smaller computational effort [3].

Nevertheless, in the framework of the progressive collapse, the literature is quite poor and the topic requires an in-depth investigation.

Another powerful tool for detecting potential instability risks affecting structures and infrastructures is Structural Health Monitoring (SHM), based on fully automated analysis of data continuously acquired by contact or contactless sensing systems [4].

SHM is indeed an effective practice to gain information about the condition of buildings and infrastructures and to make an early detection of damages and a cost-effective management of maintenance activities.

In this context, the development of new techniques based on multidisciplinary approaches applied to multi-sensing monitoring data is essential. In the last years, synergies between engineering structural analysis, novel sensing systems, data science and artificial intelligence are gaining much interest. In this framework, a new promising and challenging strategy involves the automated analysis of data provided by remote sensing technologies, in particular synthetic aperture radar interferometry (InSAR), based on the processing of a series of SAR images acquired by satellites orbiting at more than 500 km above the Earth's surface [5].

By applying advanced InSAR processing techniques (such as Persistent Scatterer Pair [6] and SAR Tomography [7]) to high-resolution SAR images, it is possible to collect a large amount of measurement points over each single building or each single bridge without installing sensors nor even accessing the structure, guaranteeing millimetric precision in the displacement evaluation.

In any case, there are currently no adequate and general procedures for interpreting the results of SAR analysis on structures, therefore much research in this sense is needed.

Research objectives

The main goal of my research is to develop an innovative strategy that combines structural and collapse analysis performed through numerical modeling with an SHM satellite remote sensing technique based on InSAR analysis.

In particular, the idea is to use advanced computational techniques (based on FEM and AEM) to simulate the progressive collapse of structures for which SAR data are available, in order to interpret from a structural point of view the results of InSAR analysis.

The study of progressive collapse allows identifying the most critical structural elements, which failure could generate a local or global collapse.

On the other hand, InSAR technology allows to follow the temporal evolution of slow deformations affecting the structure.

Through the interaction between numerical analysis and structural monitoring performed by InSAR technique, we want to understand if the measured displacements indicate a progression towards a critical condition for the structure, and if anomalies in deformation trends have to be considered dangerous or not, in order to effectively anticipate failure conditions associated to slow structural movements.

A procedure to automatically extract as much information as possible from SAR data will be developed, in order to detect potential structural instabilities.

This method also serves the purpose to identify the parts of the structure where to concentrate in-situ sensors and to trigger in-situ inspections, with clear benefits in terms of both time and resource management.

In the application to multi-span bridges, a new methodology for the analysis and interpretation of SAR data will be proposed, with the aim of automatically detecting any deviation with respect to a configuration that is considered as stable.

Methodology

Computational methods will be developed using two different approaches, based on FE and AE methods, respectively, including calibration through experimental data or literature studies results. Collapse analyses of selected case studies will be carried out assuming the failure of different structural elements, and the results related to the two methodologies will be compared, in order to understand their potential and limits in this field of application and to highlight the output differences in terms of structural behavior and collapse mechanism.

In parallel, a new method for SAR data processing in application to multi-span bridges will be developed, implementing a procedure to reconstruct the vertical and horizontal (East- West) components of the displacement vectors, being available for the same area satellite acquisitions in both ascending and descending observation geometries. Movements of the deck during the observation period will be reconstructed and cleansed from seasonal effects through an analytical separation technique, in order to be able to discriminate and identify any potentially unstable structural movement.

An inverse problem combininig collapse analyis and SAR-based monitoring will be formulated to achieve a multidisciplinary SHM strategy, in which displacement measurements obtained through SAR analysis become the input of the problem, the otuput being an interpretation and classification of such movements, particularly highlighting potentially critical conditions, in the light of the information given by the numerical analysis.

A validation of the methodology will be performed on two illustrative case studies, chosen as meaningful in terms of structural type and characteristics of the materials.

Expected results

The overarching expected result of this research work is to fully understand the stability prediction capabilities that can be associated with InSAR measurements, and to achieve an automated or semi-automated detection of critical conditions based on structural understanding and numerical modeling.

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