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XIX ANIDIS Conference, Seismic Engineering in Italy

Experimental tests for seismic assessment of ventilated façades

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Abstract

Ventilated facades are currently one of the most used technologies for external envelope of buildings. This kind of external cladding offers many advantages in terms of energy saving, sound insulation, protection of the structures, and has also a considerable architectural value. However, these nonstructural components must have suitable features to ensure their integrity in case of earthquakes. Their damage during a seismic event can have relevant consequences, on the safety of human life, on the operability of strategic buildings and can also have a significant economic impact related to post-earthquake retrofit actions. The aforementioned reasons paved the way to several studies referring to the evaluation of seismic behavior of such components, especially by means of experimental tests, even if up to now no standard procedures for seismic assessment of ventilated facades are available in Europe. This paper focuses on an experimental campaign carried out on a ventilated façade sample, 2.4 m wide and 4 m high. An innovative seismic test facility, located at the Construction Technologies Institute (ITC) of the National Research Council of Italy (CNR) in San Giuliano Milanese (Milan), is used to perform both quasi-static and dynamic tests on the sample.
Results of the tests performed by using existing experimental procedures for in-plane crescendo tests, i.e. AAMA 501.4 (2009), are compared with those obtained by applying a new loading protocol proposed by the Authors. The innovative aspect of the latter consists in the introduction of test frequencies closer to those of the buildings usually hosting this kind of façades and then obtaining a more realistic behaviour of the tested specimen. The obtained results will be the basis for the definition of harmonized assessment methods for the seismic evaluation of ventilated façades to be possibly introduced in harmonized European technical specifications.

Keywords: ventilated façade, non-structural elements, seismic performance, experimental tests

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1. Introduction

The research of more and more innovative systems for building envelope, especially in terms of energy saving, has increasingly encouraged the use of ventilated façades over recent years. These systems are counted in the category of non-structural components and, like for many other non-structural components, their seismic behavior needs to be deeply investigated. Sometimes buildings, which had not experienced structural damage after seismic events, were compromised because of serious failures of non-structural components like internal partitions, ceilings and cladding panels, which have been shown to be vulnerable also to moderate earthquakes (Price et al., 2012, Magliulo et al., 2014). The collapse of partitions and façade components represents also a significant threat to the occupant and pedestrian safety, as well as a direct and indirect economic losses.

The above mentioned reasons motivated the increasing number in the last decades of research studies conducted in order to investigate the seismic behavior of such components. Magliulo et al. (2012, 2014) investigated the seismic capacity of internal plasterboard partitions by means of shaking table tests, other experimental studies concerning the seismic assessment of plasterboard partitions were conducted by Retamales et al. (2013) and Tasligedik et al. (2015), by means of quasi static tests. Also for precast concrete panels, usually used as cladding system of industrial and commercial buildings, several research studies about seismic behavior of these components are available in literature (Colombo and Toniolo (2010), Biondini et al (2013), Ercolino et al. (2018), Negro and Tornaghi (2017)).

Few studies are available about the seismic behavior of ventilated façades and consequently building codes are not sufficiently exhaustive regarding their design and verification under earthquake loadings.

For such reasons this paper focuses on a part of an experimental campaign aimed at the seismic assessment of ventilated façades. The selected specimen, whose height is equal to the distance between two consecutive floors, was subjected to two static tests in the plane of the components, according to the loading protocol proposed by AAMA 501.4 (2009) and one "crescendo" test. The latter is carried out by loading the specimen with increasing displacements, in the plane of the components, but the displacements are applied dynamically with two different frequencies, typical of the buildings to which the ventilated façade are attached. This new crescendo test, proposed by the Authors, is a modification of the crescendo test included in AAMA 501.6 (2018), that specifically refers to glazed panels and curtain walls. The tests are performed by means a new testing facility specially designed for investigate the seismic behaviour of plane components. The main results are presented in this paper.

Furthermore, since no European codes are at moment available aimed at the investigation of seismic behaviour of ventilated facades, one of the objective of the presented work is the definition of harmonized assessment method to be possibly included in harmonized European technical specifications. Indeed, the modern technical codes should provide both appropriate experimental and analysis methods to define the seismic capacity of nonstructural components and establish design criteria aimed at protecting the secondary structure from the effects of the earthquakes.

2. Experimental campaign

The experimental campaign herein reported concerns the seismic assessment of a ventilated façade system, which features are described in §2.2, by means of an innovative seismic test facility, described in §2.1. The seismic assessment is pursued by performing in-plane static and dynamic tests, according to what is reported in §2.3.

The objective is the evaluation of the damage recorded on the specimen during the tests and the correlation of such damage with applied inter-story drifts.

2.1. Seismic test facility

The test equipment, used to perform the afore mentioned seismic tests on the ventilated facade system, is located at the Institute for Construction Technologies (ITC) of the National Research Council (CNR) in San Giuliano Milanese (MI). The seismic test facility allows the installation of full scale façade systems up to 5600 mm (width) by 8000 mm (height). The specimens can be mounted to the steel framed structure at three levels: a fixed beam at the base and two movable beams at the second and third levels (Fig. 1a). All beams are equipped with anchoring channels, in order to be able to install various types of facade systems, walls and partitions. The moving beams are connected to a system of dynamically controlled hydraulic actuators. A mechanical lifting system of the beams allows to obtain different inter-story heights. The displacements in the plane of the façade are produced by a double rod hydraulic actuator, positioned on each mobile beam, with a load capacity of 200 kN and a maximum displacement of ± 85 mm. Out-of-plane displacements are produced by two double rod actuators (for each beam) with a load capacity of 100 kN and a maximum displacement of ± 85 mm (Fig. 1a). The two actuators can work in push-pull to obtain inter- story displacements (2-3 levels) up to ± 170 mm. It is possible to apply displacements in dynamic condition with high frequencies. The actuators are interfaced with a control system that allows to apply desired displacement histories, amplitudes, frequencies and the number of cycles.

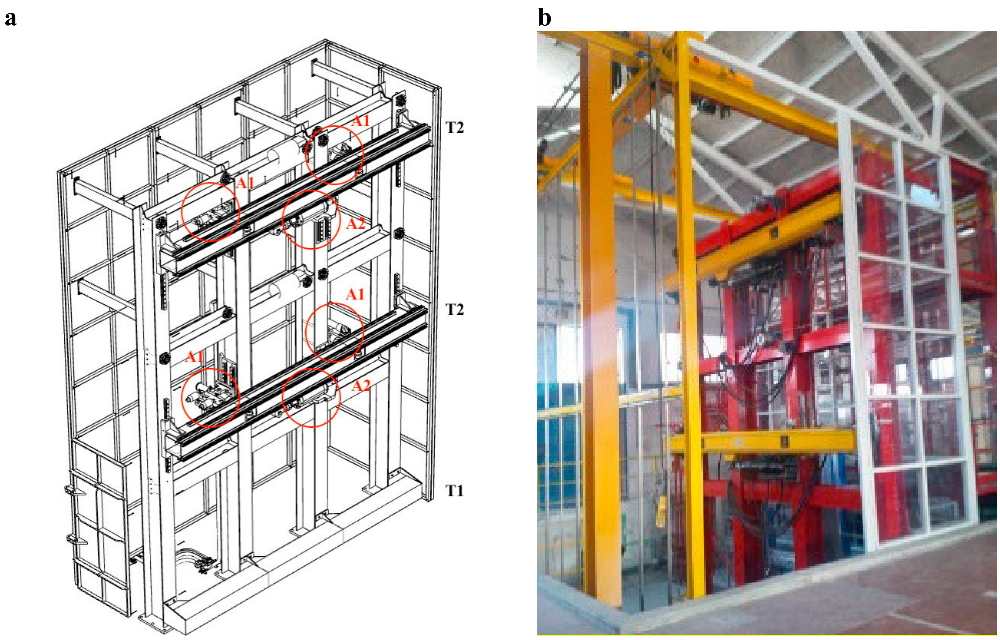

Fig. 1. (a) Scheme of the test equipment (T1 - fixed beam, T2 - moving beams, A1 - out of plane actuators, A2 - in plane actuators) and (b) overall view of the seismic test facility

2.2. Tested specimen and test setup

The sample of ventilated facade system subject to seismic tests is 2405 mm wide, 4128 mm high (Fig. 2a) and is made up of three vertical studs, 1200 mm spaced, to which eight porcelain stoneware panels are connected by means of fixing hooks (named “S10 Hook” in Fig. 2b).

With the aim of connecting the specimen to the seismic test facility simulating real installation conditions, the yellow beams of the test facility are moved to reach the required inter-story height of two consecutive building floors. Then, the specimen’s vertical studs are connected to black tubular steel profiles (sub-structure in Fig. 3a), rigidly linked to the yellow beams, simulating the infill system to which the ventilated façades are usually connected. Finally, the cladding panels are attached (Fig. 3b) by means of both structural silicone and fixing hooks.

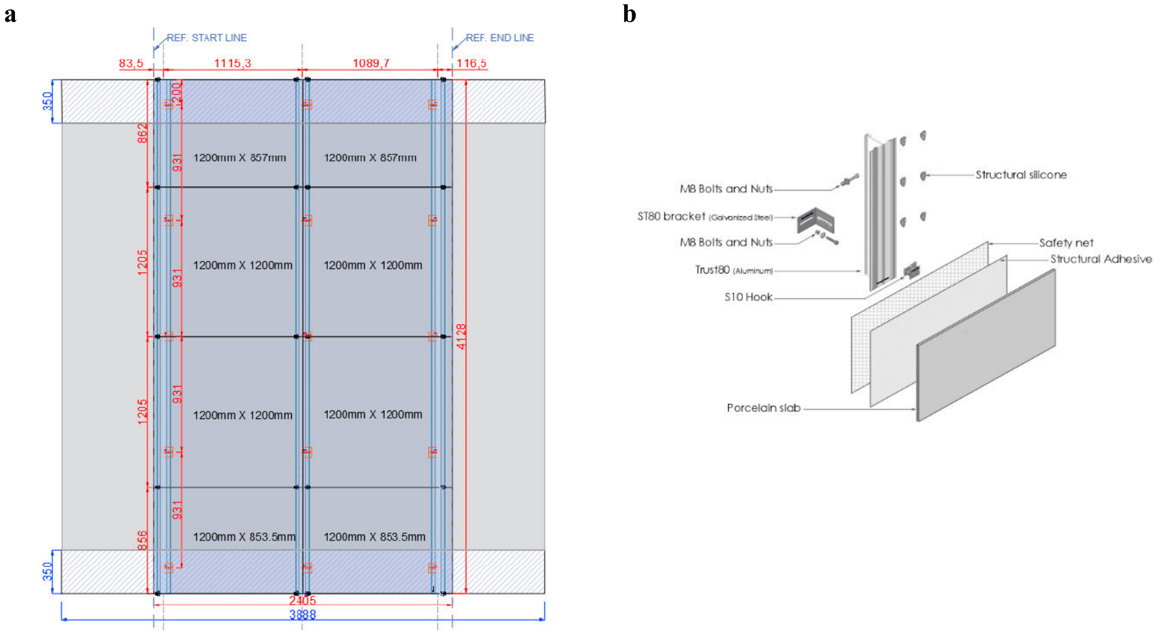

Fig. 2. (a) Scheme of the tested sample and (b) detail of the components.

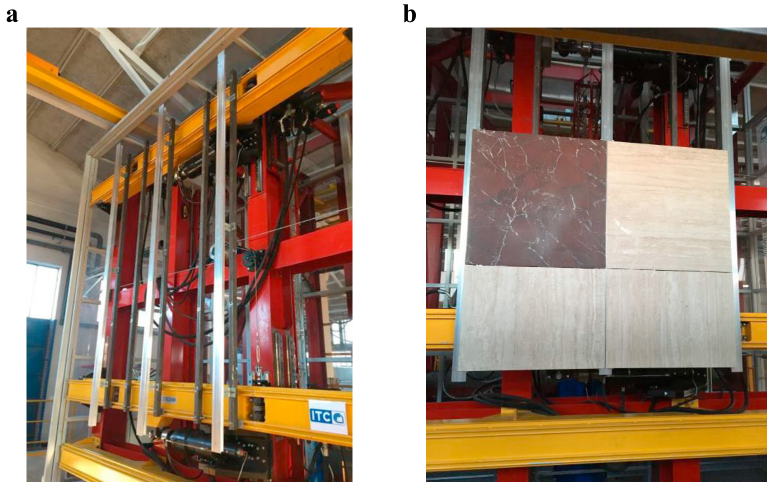

Fig. 3. (a) View of the sub-structure which the ventilated façade is connected to and (b) a view of the panels mounting phase.

2.3. Loading protocols

The experimental campaign consists of two static tests and one “crescendo” test, carried out in the plane of the specimen.

The static tests were carried out according to the provisions of the American Standard AAMA 501.4 (2009). Each test consists of three full cycles of an established displacement value applied to the base of the supporting structure, in the plane of the component, in order to simulate the inter-story drift induced on the structure by earthquake or wind.

A cycle is defined as a full displacement in one direction, back to the starting position, full displacement in the opposite direction and back to the originating point. There is no specific requirement on the duration of the single cycle, but the displacements must be applied in a quasi-static manner in order to easily detect any damage to the sample and associate them with the value of the inter-story drift that generated them.

The main features of these tests are listed below:

- the first one provides for a maximum displacement of 26.2 mm and a displacement rate of 0.2 mm/sec (Fig. 4a);
- the second one provides for a maximum displacement of 31.5 mm and a displacement rate of 0.25 mm/sec (Fig. 4b);

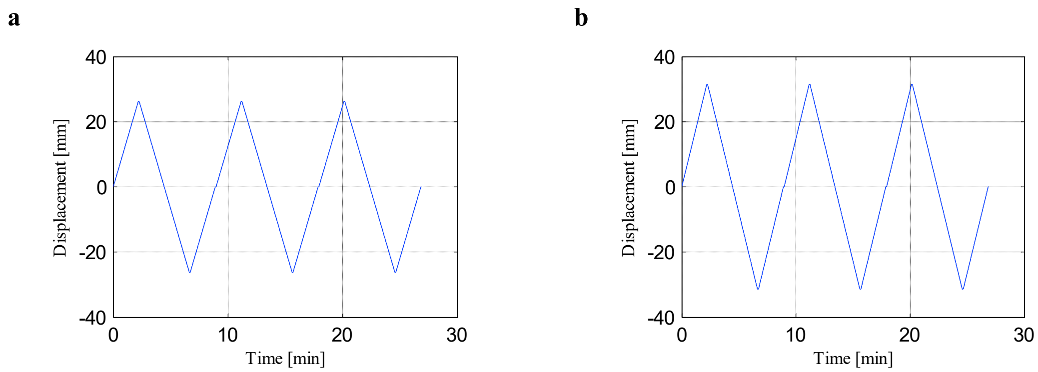

Fig. 4. Input protocol of the (a) first and (b) second test according to AAMA 501.4

The loading profiles shown in Fig. 4 are applied at the yellow beam of the seismic test facility described in § 2.1, at the base of the façade specimen, shown in Fig. 1a.

The third test was performed by applying a "new" input protocol developed by the Authors starting from the "crescendo test" proposed by AAMA 501.6. The AAMA 501.6 is conceived as a complement to AAMA 501.4, since the latter focuses primarily on change of serviceability of the façade system, for example in terms of air and water leakage, after the application of static horizontal displacements. Instead, the former focuses on determining the fallout of the panels from the façade system. It consists of a concatenated series of "rump up" intervals and "constant amplitude" intervals made up of four sinusoidal cycles each (see Fig. 5). The crescendo test shall be performed at a frequency of 0.8 Hz for total applied displacements of ±75 mm, and 0.4 Hz for total applied displacements greater than 75 mm. The test shall be run continuously until the first of the following condition exists: (1) fallout of any cladding elements of the cladding wall; (2) the maximum applied displacement is equal to ± 150 mm.

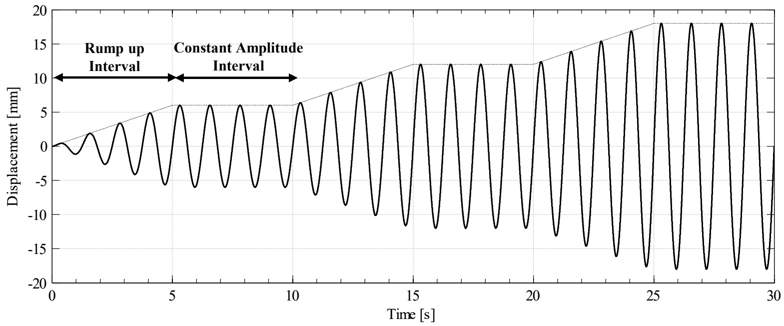

Fig. 5. “Rump-up” interval and “constant amplitude” intervals of crescendo Test

Since the AAMA 501.6 “crescendo tests” was especially developed for large façade glass panels and the loading protocol was obtained from the modeling of one-story masonry building which cladding glass panel are attached to, the Author propose a “new” crescendo test in which the displacements are applied in the plane of the façade system according to the procedure of AAMA 501.6, but at frequencies closer to those of the buildings usually hosting this kind of façades, in order to obtain a more realistic behavior of the tested specimen. Hence, the crescendo test shall be performed at a frequency of 2 Hz for total applied in-plane displacements (drift amplitude) of ±75 mm, and 1 Hz for total applied in-plane displacements greater than 75 mm. In summary, the third test was carried out by applying the loading protocol shown in Fig. 6. The total required displacement is obtained by moving, instant by instant, the top and the bottom yellow beams of the testing facility in opposite direction, each of them with a half displacement value.

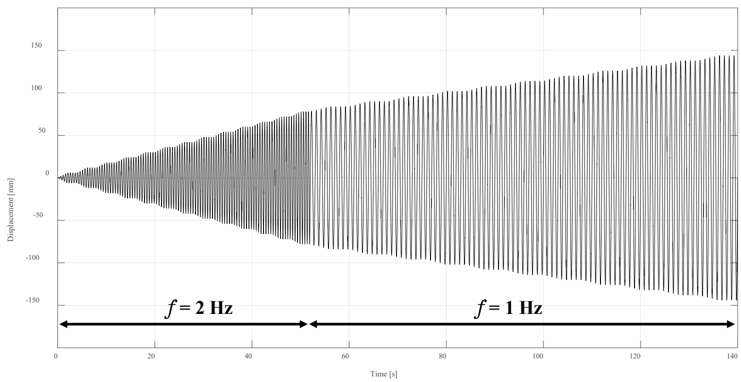

Fig. 6. Loading protocol of “new” crescendo test

3. Results and discussion

The results are reported in terms of damage observed on the specimen during the tests.

The two in-plane static tests point out that the sample does not show any damage for any level of displacement imposed at the lower beam of the test equipment:

- during the first test, i.e. up to displacements of ±26.2 mm, therefore for inter-story drift ratios equal to 0.6% of the height of the specimen, no damage can be found. At the end of the test it is observed that the alignment of the porcelain stoneware panels is not changed.

- during the second test, i.e. up to displacements of ±31.5 mm, therefore for inter-story drift ratios equal to 0.8% of the height of the specimen, no damage can be found. Also in this case, at the end of the test the alignment of the cladding panels is not changed.

When the "new" crescendo test was carried out, the following damages were observed:

- the first damage consisted in the fall down of a small portion of a tile in correspondence of the corner (Fig. 7a), i.e. where it is connected by the hook to the stud. It occurred for ±35 mm applied displacement, corresponding to 1.10% inter-story drift;
- for an applied displacement of ±40 mm (inter-story drift = 1.25%) the detachment of the same portion of another tile is observed;
- at ±47 mm applied displacement (drift = 1.47%) a further detachment of a portion of the tile is observed, always at the connection with the stud. All the fallen portions of the panel were located on the same vertical, i.e. in correspondence with their connections to the same external stud (on the right of the façade specimen).
- for a maximum applied displacements of ±53 mm (1.65%) and beyond, a strong out-of-plane rotation of the above mentioned vertical stud was observed.

The test was performed up to the maximum displacement provided by the proposed loading protocol, i.e. ±150 mm. Inspecting the back of the specimen at the end of the test, it was observed the failure of the brackets connecting the left and central studs with the sub-structure (Fig. 7b). These two studs did not rotate during the test. The rotation of the right side stud was due, on the other hand, to the bolts coming out of the brackets (Fig. 7c). These brackets resulted not damaged.

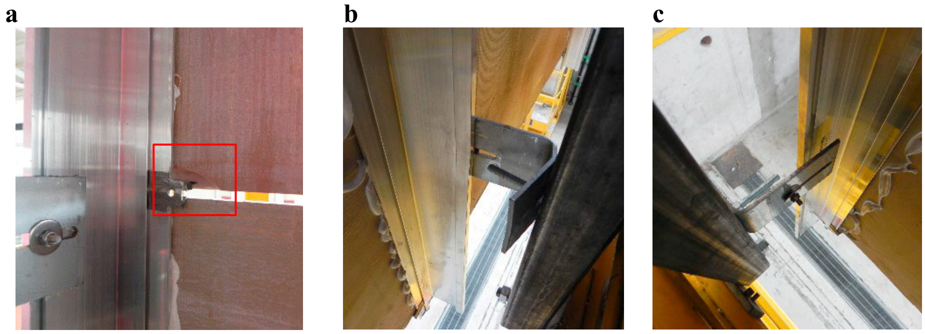

Fig. 7. Damages of the specimen observed during the "new" crescendo test: (a) detachment of a small portion of a tile in the corner, (b) yielding of the brackets connecting the left and central studs to the substructure and (c) bolts coming out of the brackets connecting the right side stud to the substructure

4. Conclusions

The present work deals with the seismic assessment of a specimen representing a portion of a ventilated façade. In particular, the paper focuses on the description of the test setup and equipment used to carry out static and dynamic tests in the plane of the component and in the presentation of a new test method for dynamic crescendo test.

The experimental results show the applicability of the proposed loading protocol and the possibility to include it in a more comprehensive technical specification about the seismic assessment of ventilated façade.

Acknowledgements

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XIX ANIDIS Conference, Seismic Engineering in Italy

Preface

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Keywords: Preface, ANIDIS Conference, Seismic Engineering.

1. Preface

The Italian real estate assets, in particular the historical and infrastructural ones, continue to show their fragility in relation to seismic events, as dramatically highlighted by the recent earthquakes in Emilia Romagna (2012) and Central Italy (2016). For this reason, in recent years, scholars have promoted several initiatives at a scientific, technical and regulatory level, in order to improve the seismic performance of new buildings and to mitigate the seismic risk of the existing building and infrastructural heritage. In particular, the New Technical Standards for Constructions (2018), the Explanatory Circular (2019) and the Guidelines for the Seismic Risk Classification of Constructions (2017) were published, increasingly focusing on the issue of seismic risk.

ANIDIS (Italian National Association of Seismic Engineering) is an Association that has the following aims: (i) To promote, encourage and disseminate in Italy, also through the publication and sale of specific documents, the culture concerning seismic problems among professionals working in sectors: Structural Engineering, Geotechnics, Geology, Urban Planning, Architecture, Restoration, Civil Protection and Environmental Protection; (ii) Identify scientific research topics deriving from professional practice and promote their study; (iii) Establish and maintain national and international contacts between those who are interested in the problems referred to in point (i) and with the Associations having similar aims; (iv) Collaborate with the competent authorities in the drafting of rules and regulations concerning seismic engineering.

ANIDIS managed to organize in Turin its biannual meeting. The XIX ANIDIS meeting took place in the wonderful venue of the Politecnico di Torino in September 11-15, 2022.

It is possible to state that it was a successful event: during the conference more than 300 presentations were showed and 6 plenary lectures were carried out by M. Sarkisian (SOM, USA), F. Ballio (Politecnico di Milano, Italy), F. Braga (Università di Roma La Sapienza, Italy), W. Salvatore (Università di Pisa, Italy) and E. Chatzi (ETH Zurich, Switzerland).

The presentations were scheduled in 16 General Sessions and 18 Special Sessions, covering a wide range of topics related to theory, modelling and experiments in the field of Seismic Engineering. The topics covered among others: Seismic hazard, Soil dynamics and seismic geotechnics, Dynamic soil-structure interaction, Vulnerability and seismic risk, Safety and seismic risk,

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Technical standards and design/verification methods, Methods of analysis, modelling and capacity models, Reinforced concrete buildings, Masonry and reinforced masonry constructions, Constructions in steel and mixed steel-concrete, Wooden buildings, Prefabricated buildings, Traditional and innovative materials, Bridges, tunnels and strategic and special structures, Non-structural elements (technical networks) and plants, Testing, diagnostics and monitoring of structures and infrastructures, Analysis and reduction of the seismic risk of buildings: intervention strategies, methods and techniques, Reinforced concrete buildings, Masonry and reinforced masonry constructions, Constructions in steel and mixed steel-concrete, Wooden buildings, Prefabricated buildings, Evaluation and improvement of the structural behaviour of the listed cultural heritage, Examples of achievements: architecture and structures, recent projects and constructions, Passive, semi-active and active protection of structures and systems, Big Data and IoT for existing structures and infrastructures.

The constructive and vibrant discussions taken at the end of each presentation were a further confirmation of the high scientific quality of the event as well as of the significant level of interactions among the participants.

This special issue of Procedia Structural Integrity collects about 300 papers related to the presentations given during the XIX ANIDIS Conference.

The Guest Editors of this special issue wish to warmly thank all the authors for the quality of their contributions.