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EXPERIMENTAL SEISMIC ASSESSMENT OF SANDWICH PANELS FOR FAÇADE SYSTEMS

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Abstract

The assessment of non-structural elements seismic performance is a topic of great importance in earthquake engineering, due to the high vulnerability of such components, whose damage during an earthquake can significantly affect the overall performance of the hosting building. Experimental testing represents one of the most reliable method for the evaluation of seismic capacity of non-structural components.
Within this context, this paper presents the main results of experimental tests conducted on a specific façade system consisting of sandwich panels, usually used as envelope solution for commercial, industrial and hospital buildings. The tests are part of a research project, named ENRICH (Enhancing the resilience of Italian healthcare and hospital facilities), whose main objective was enhancing the resilience of healthcare facilities, regarding both functional adaptivity and seismic performance of nonstructural components.
In particular, the study deals with the assessment of the seismic performances of the selected façade system by means of quasi-static and dynamic tests carried out on full-scale specimens, both in-plane and out-of-plane directions. The tests were performed using an advanced equipment located at the Institute for Construction Technologies (ITC) of the Italian National Research Council (CNR), that allows seismic testing of plane elements, such as internal partitions or façade systems.
Following the description of the test setup, the paper shows the seismic response observed during the test sequence, reporting the results in terms of vibration frequencies, recorded accelerations in specific points of the specimen and damage detection.
The results show that the peak acceleration in the middle of the panel increases significantly compared to the input values, reaching more than twice the input levels. In addition, the main damage was observed in the façade connection system, demonstrating to be the most vulnerable part of the system.

Keywords: Non-structural elements, Façade systems, Experimental seismic assessment, Dynamic tests, Quasi-static tests.

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1 INTRODUCTION

Seismic vulnerability of non-structural elements is an issue that has become increasingly important in recent years, both for its safety implications and for its economic aspects. In fact, non-structural elements constitute a significant part of the overall cost of a building. As reported by Taghavi and Miranda [1], this incidence ranges from 48% for hospitals, to 62% for offices and 70% for hotels.

Several studies have also shown that, after a seismic event, damage to non-structural elements frequently exceeds structural damage ([2]). These damages include both direct material damage and indirect losses, which are more complex to quantify. Recent seismic events in Italy, such as the 2012 Emilia and 2016 Central Italy earthquakes, have highlighted the seismic vulnerability of non-structural elements; indeed, in addition to structural damage, extensive damage to such elements, including infill panels and partitions, has been observed ([3]).

Several experimental campaigns have been conducted to evaluate the seismic behavior of internal partitions. Magliulo et al. [4] examined the seismic behavior of internal partitions using shaking table tests and found that damage occurs mainly at joints. The authors also observed a change in dynamic characteristics, which corresponded to the damage found. Petrone et al. [5], on the other hand, performed quasi-static tests on internal plasterboard partitions, finding that the first damage appears in the joints and perimeters between panels. Petrone et al. [6] conducted shaking table tests on temporary partition walls, obtaining similar results, with damage localized mainly in the joints of the system.

Façade systems fall into the category of non-structural elements, and their collapse during a seismic event represents a significant risk to both human safety and direct and indirect economic losses. Although several studies focus on the seismic behavior of interior partitions or prefabricated panels ([7, 8, 9, 10]), only a few analyze specifically the seismic behavior of façade systems ([11]).

In the context of the ENRICH project (Enhancing the resilience of Italian healthcare and hospital facilities), which explores the seismic behavior of non-structural elements in hospital structures, the study of the seismic behavior of interior partitions, as well as exterior façades, is of crucial importance.

This study focuses on the seismic behavior of façade systems made with sandwich panels. A vertical shaking testing equipment, located at the ITC-CNR (Institute for Construction Technologies of Italian National Research Council), was used for experimentation, which simulates inter-story seismic action, allowing to evaluate the response of the specimen both in-plane and out-of-plane directions. Specifically, the test protocol (described in [12]) involves a test sequence that includes random tests, tests with imposed in-plane displacements (*Crescendo test*) and dynamic out-of-plane tests. This paper presents the results obtained, focusing on the accelerations measured in the different parts of the panel and on the observed frequencies. In addition, a discussion of the damage state identified at the end of the test is provided.

2 DESCRIPTION OF EXPERIMENTAL CAMPAIGN

This section provides information about the experimental tests, including the geometrical features of the tested specimen, a description of the testing facility used for the seismic assessment, and an overview of the test setup and instrumentation. Additionally, details regarding the loading protocols are provided.

2.1 Testing machine

The testing machine used to perform the experimental tests is located at the Institute for Construction Technologies (ITC) of the National Research Council (CNR) in San Giuliano Milanese (MI). This apparatus (Figure 1) allows the installation of full-scale plane systems up to 5600 mm (width) and, basically, of any height (considering the exploitable height of 8000 mm). The equipment consists of a steel framed structure at three levels, with a fixed beam at the base and two moveable beams at the second and third levels. The moveable 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 both directions (in-plane and out-of-plane) of the tested component are generated by a double rod hydraulic actuator (A1 and A2 in Figure 1), positioned on each movable beam. The actuator has a load capacity of 200 kN for in-plane displacements and 100 kN for out-of-plane displacements, with a maximum displacement of ± 85 mm and a frequency of up to 30 Hz.

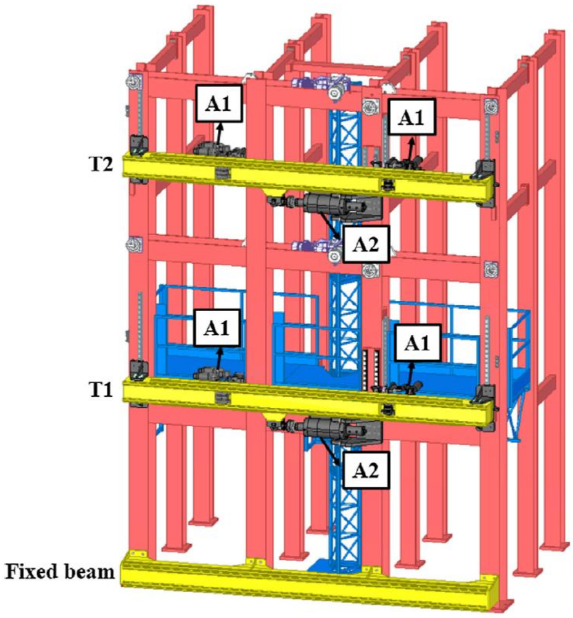


Figure 1: ITC-CNR test facility.

2.2 Façade system with sandwich panels and test setup

The tested sample consists of an external wall cladding made of sandwich panels with a rock wool insulation layer. The sample, shown in Figure 2, comprises four panels: two central full panels, measuring 3000 x 1000 x 80 mm, and two external panels measuring 3000 x 400 x 80 mm.

Each sandwich panel (Figure 3) is composed of an external sheet made of pre-painted galvanized steel with a thickness of 0.6 mm and an internal sheet of the same material with a thickness of 0.5 mm. The insulation is provided by a 80 mm thick rock wool layer, which is self-adhered to the steel sheet using polyurethane glue. In addition, an 8 mm thick ecological fiber cement board, mechanically fastened to the external metal sheet of the panel is provided.

They were mounted vertically with a male-female interlocking system and fixed to the top and the bottom beams of the testing machine by means of L-shaped steel brackets (Figure 4).

In order to observe the behavior of the specimen during the test, the instrumentation shown in Figure 5 was positioned on the panel. Specifically, accelerometers were placed at the brackets (LB on the lower and UB on the upper bracket), at the base (B), and at the center of mass (CM) of the panel to measure the response of the specimen. Additionally, an accelerometer was placed on the lower beam (Input) to measure the input signal.

Figure 2: View of the façade system with sandwich panels specimen.

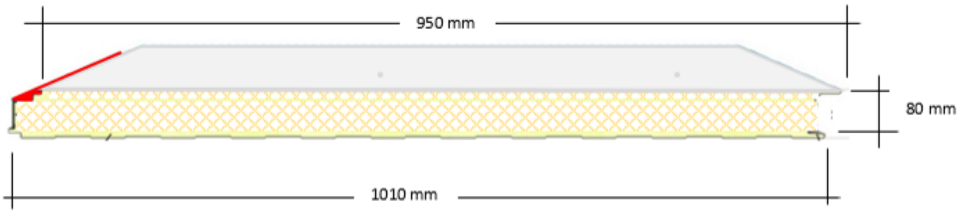


Figure 3: Sandwich panels specimen.

Figure 4: Panel connections (L-shaped steel bracket).

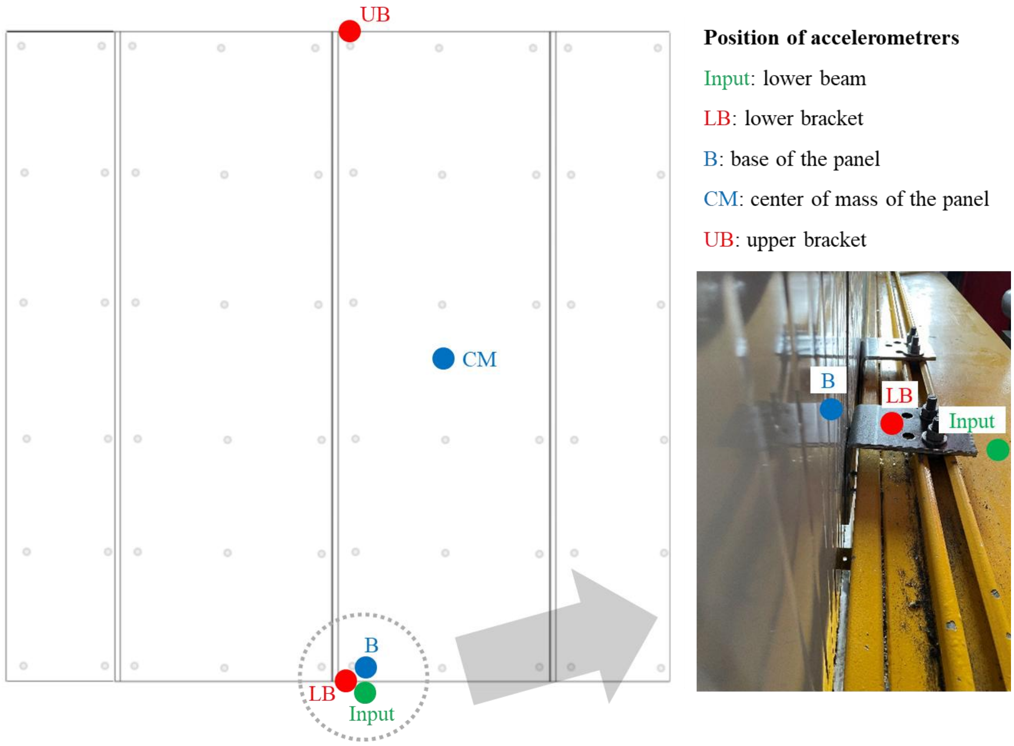


Figure 5: Position of accelerometers in the specimen.

2.3 Input protocols

The assessment of the seismic capacity of the specimen was carried out by analysing the in-plane and the out-of-plane behaviour separately.

In particular, the in-plane behavior was assessed through the *Crescendo test* while the out-of-plane behavior by means of the *Dynamic test*s, both of them according to the procedure defined in Bonati et al [12].

For this specific case, in order to evaluate the influence of damage due to the in-plane deformations during the out-of-plane dynamic tests, a specific test sequence composed of three *Phases* was performed. During *Phase 1*, tests involving in-plane displacements were conducted (*Crescendo test*), with incremental drift values applied to the system ranging from 0.2% to 1.4% (Figure 6). *Crescendo tests* consists of a series of constant and incremental amplitude intervals imposed with a frequency of 2 Hz (Figure 7a).

Then, *Phase 2* of the test focused on dynamic out-of-plane (OOP) tests. The time history of the spectrum-compatible acceleration is shown in Figure 7b. The reference acceleration (applied to both the base and top of the panel), represented by the accelerogram shown in Figure 7b, was scaled to values between 5% and 70% of the maximum acceleration. Before performing *Phase 1* and after *Phase 2* of the testing sequence, random tests (RND1 and RND2, respectively) were performed with the purpose of identifying the vibration frequencies of the system (Figure 6).

At the end of *Phase 2*, the additional Random test (RND2) was performed to detect any changes in the vibration frequencies of the system and, consequently, to identify potential structural damage. Finally, *Phase 3* involved the application of an in-plane crescendo test, with incremental drift values ranging from 1.6% to 2%.

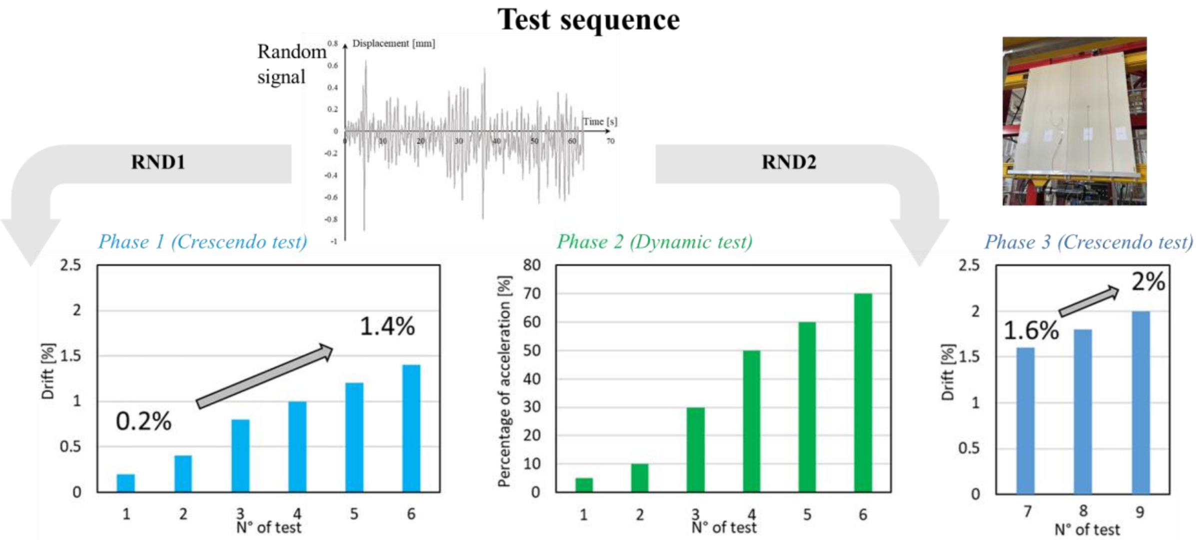
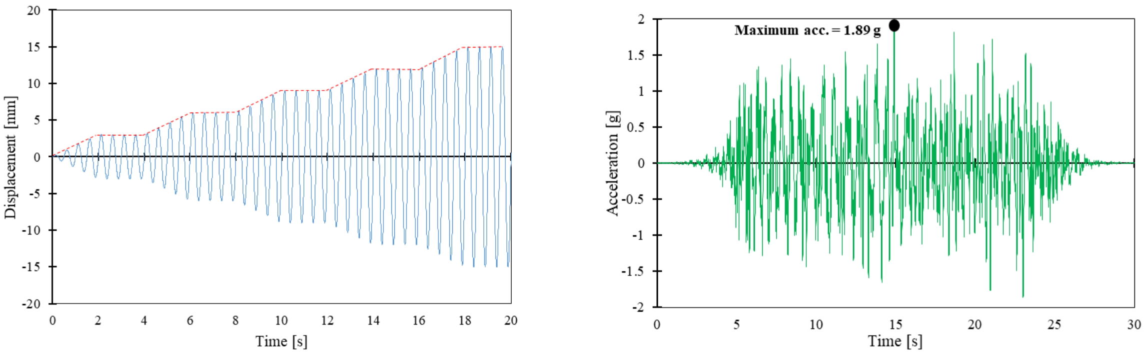


Figure 6: Sequence of tests performed



(a) (b)

Figure 7: Reference signals for (a) *Crescendo test* (in-plane) and (b) *Dynamic test* (out-of-plane).

3 TEST RESULTS

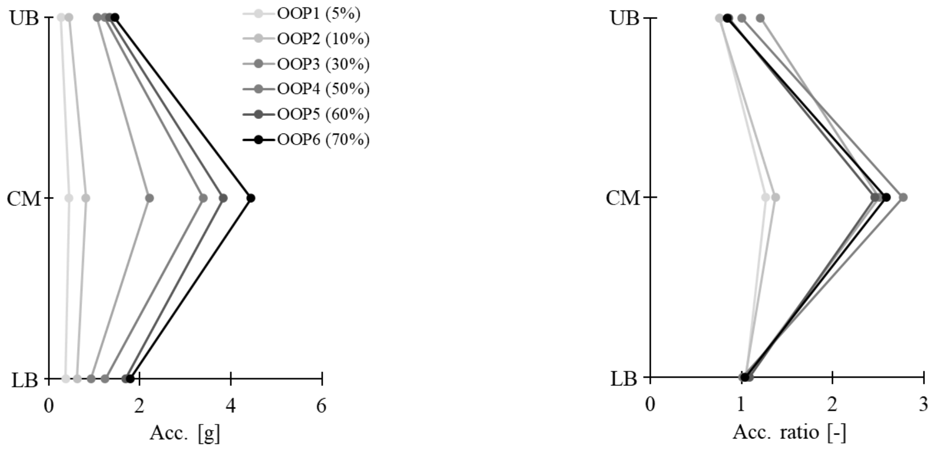
This section presents the results observed in the tests, in terms of panel acceleration profile and transfer functions.

During *Phase 1*, corresponding to Crescendo Test up to 1.4% of drift no visible damage was recorded in the specimen.

By analyzing the results of *Phase 2* in terms of recorded accelerations, the following considerations can be drawn.

Figure 8 shows the maximum absolute and relative acceleration values (ratio of center-of-mass to input accelerations) measured at the lower and upper brackets (LB and UB) and at the center of mass (CM) of the specimen. The results show that maximum acceleration occurs at the CM position, as expected, since the panel was constrained at both the base and top. Higher acceleration is observed as a function of increasing input acceleration, in line with expectations. Figure 8b reveals a significant difference between the OOP2 (10%) and OOP3 (30%) analyses, and beyond that, no significant increases in acceleration amplification (relative to the input signal) are observed.

Figure 9 provides a detailed view of the CM behavior of the panel during OOP analysis, showing its acceleration peaks. It is observed that between the second and third dynamic OOP tests (i.e., between 10% and 30% of the OOP signal), there is a sudden increase in the acceleration of the center of mass, probably due to damage. Beyond this point, the acceleration values remain approximately constant.



(a) (b)

Figure 8: Recorded acceleration profiles along the panel height in absolute terms (a) or relative to the input signal (b)

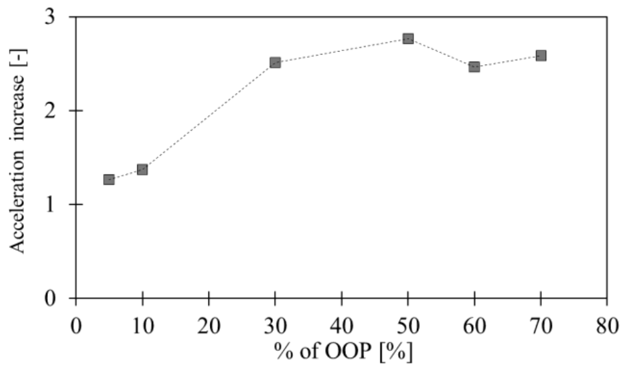


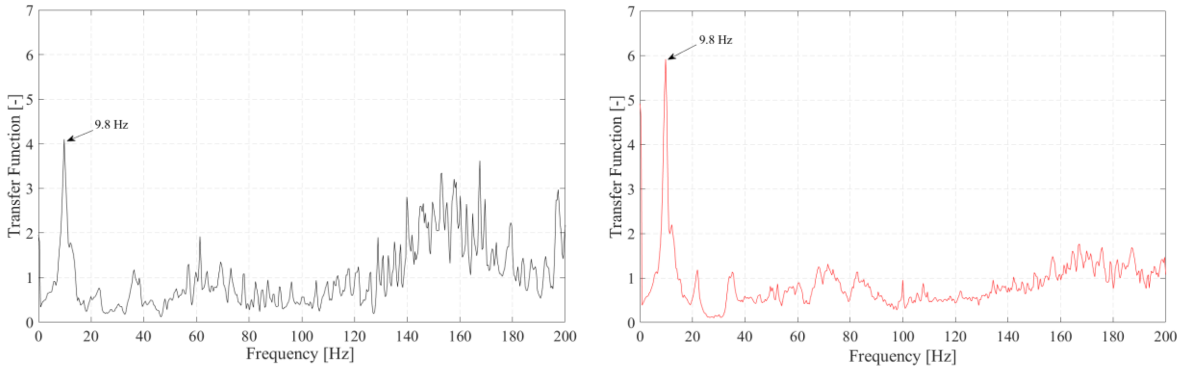
Figure 9: Acceleration ratio in the center of mass (CM)

To investigate the dynamic properties of the panels, the Transfer Functions of random test results, calculated from the CM response of the panel, have been considered (Figure 10).

The results show that the main vibration frequency of the system is 9.8 Hz (i.e., the period is 0.1 s) and is the same in both tests. However, two differences emerge between the test conducted before *Phase 1* (RND1) and after *Phase 2* (RND2). The first difference is related to the intensity of the Transfer Function corresponding to the main frequency, which is higher in RND2. In contrast, the second difference is related to the intensity of the function at high frequencies, which is significantly higher in RND1. These two aspects suggest a change in the dynamic behavior of the panel, confirming the results previously shown.

Figure 11 shows the Transfer Functions in terms of the ratio of the signal measured at the base of the panel (B) to that measured at the CM. The functions (RND1 and RND2) exhibit distinct characteristics. In particular, RND1 shows high intensity distributed over a wide frequency range (with high values, approximately from 140 Hz to 180 Hz). In contrast, RND2 shows a main peak around 30 Hz, while it takes lower values for the other frequencies considered. This result suggests that internal panel damage occurred between the two random tests and it increased the range of frequencies in which the response in the CM compared with that at the base is significant.

Finally, Figure 12 illustrates the damage detected at the end of the test. The visible damage is concentrated in the panel, particularly in the connections between the panel and the bracket (showing deformation of the holes at the panel attachment points). The brackets exhibit no evidence of damage.



(a) (b)

Figure 10: Transfer function for the random analysis RND1 (a) and RND2 (b), performed before *Phase 1* and after *Phase 2* respectively

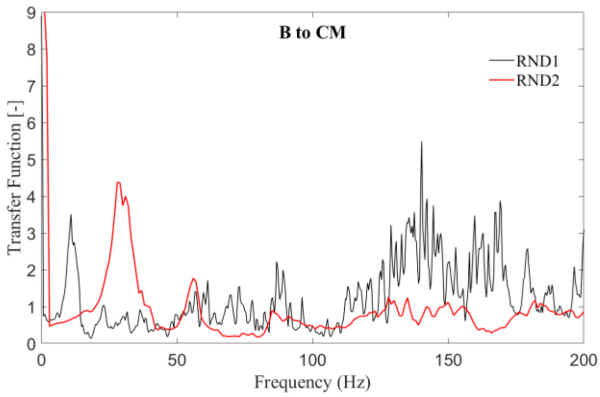


Figure 11: Transfer function in terms of ratio (B to CM) for the random analysis RND1 and RND2.

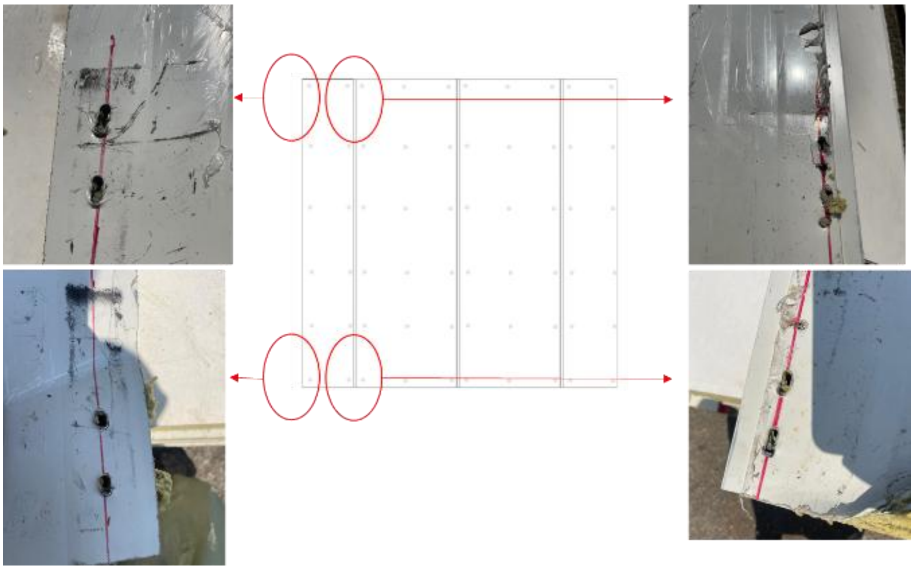


Figure 12: Damage detected in the panel at the end of the test.

4 CONCLUSIONS

The study presents the results of an experimental campaign conducted to evaluate the seismic behavior of a façade system consisting of sandwich panels. Both in-plane and out-of-plane behavior were investigated. In both cases no visible damages were detected in the panel (except for those detected at the anchor points), but the analysis of the accelerations recorded during the out-of-plane dynamic tests allows drawing the main results given below:

- the peak of panel accelerations occurs at the center of mass, where the recorded acceleration exceeds twice that of the input signal;
- the acceleration of the center of mass and the Transfer Function indicate the presence of damage that has not changed the main vibration frequency, but has affected the intensity of both the response (in terms of acceleration) and the Transfer Function, increasing its value at the main frequency and decreasing at higher frequencies;
- two types of damage were found: one internal to the panel, discovered through analysis of panel response signals related to OOP analysis, and another detected through visual inspection at the end of the test, which showed deformation at the fastening joint between the bracket and the panel.

Based on the initial results, it is unclear whether these damages are related. However, further investigation is needed to determine whether both types of damage result from the out-of-plane response of the panel, or whether the anchorage damage is due to in-plane behavior, opening the hypothesis of decoupled in-plane and out-of-plane behavior (and thus damage types) for this type of construction product.

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