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STEEL BRACING SYSTEMS TO REDUCE THE SEISMIC VULNERABILITY OF LWS SUSPENDED CEILINGS: EXPERIMENTAL CHARACTERISATION

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Abstract

Analysing the consequences of the last decades worldwide earthquakes, significant damages were recorded to the non-structural element, even for the less-intense ones. One of the most frequently reported non-structural damages is related to the failure of suspended ceilings. The seismic vulnerability of these systems could cause noteworthy economic losses associated to business and functionality interruptions. One reason for the higher vulnerability of non-structural elements can be found in the lack of seismic resistant details. In this work, the preliminary experimental response of the performance of two bracing systems designed to improve the seismic behaviour of lightweight suspended ceiling is presented. The tests on the bracing systems are carried out according to FEMA 461 loading protocol. The investigated bracing systems are tested using an universal testing machine by means of a properly designed test set-up. Moreover, the innovative test set-up allows to analyse the bracing systems performance in two different configurations for considering different possible directions of the horizontal seismic action. A total number of 20 cyclic tests are performed in order to compare the seismic behaviour of the two bracing systems in terms of strength, stiffness and damage phenomena.

Keywords: Non-structural elements, Acceleration-sensitive component, Cyclic tests, Lightweight steel, Bracing system.

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1 INTRODUCTION

During an earthquake, the most common cause of deaths and injuries is the collapse of buildings or their structural components. However, non-structural elements can also pose a serious threat to people's safety and block escape routes. Non-structural elements refer to systems and components that are not part of the main load-bearing structure, but are attached to the floors, roof, and walls of a building or industrial facility and may be subjected to large seismic forces [1]. The earthquakes that have occurred worldwide in the recent past have resulted in significant damage to non-structural elements, even in less intense earthquakes where no structural damage occurred [2]. The damage mainly involved the failure of external walls, ceilings, cladding, and building services. Within this framework suspended ceilings are an essential non-structural component in building construction, as they serve a critical function in preserving the building's functionality and aesthetic appeal. A lightweight suspended ceiling is a type of ceiling system that is hung from the structural floor slab above, by means of a specific suspension system (see Figure 1). These ceilings are typically made of lightweight materials, such as mineral fiber, gypsum, or metal tiles, which have the advantage of being designed to be easily installed and removed. Generally the installation procedure begins with the suspension system, and then the ceiling tiles are placed within the grid. The ease with which the tiles can be removed and replaced has made them very popular for commercial and industrial buildings, where there is a need for access to facilities. According to previous earthquake reports, suspended ceiling systems are susceptible to significant damage [3-5]. Since ceilings failures can result in injuries, significant economic losses, and significant disruptions to building operations, a detailed seismic performance characterization is necessary. Since the numerical study of such systems due to their complexity is still challenging, in the past numerous tests on both entire ceilings and components have been conducted [6-8]. In order to reduce the vulnerability of these non-structural component, a compression strut, connecting the main runner and the floor above, surrounded in all four major direction by a steel bracing system, could be conceived as lateral restraint.

The aim of this work is the experimental characterization of the seismic response of two bracing systems developed for reducing the seismic vulnerabilities of light weight suspended ceilings. This paper is divided in three parts; first of all, the general features of the investigated bracing systems are presented. Thus, the component-level experimental characterization performed on these systems is described. Finally, preliminary test results in terms force-displacement response and damage phenomena are presented.

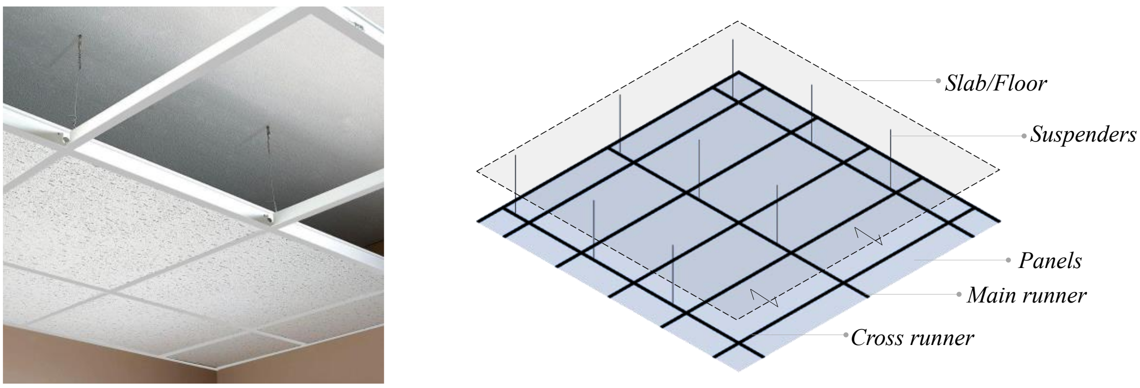
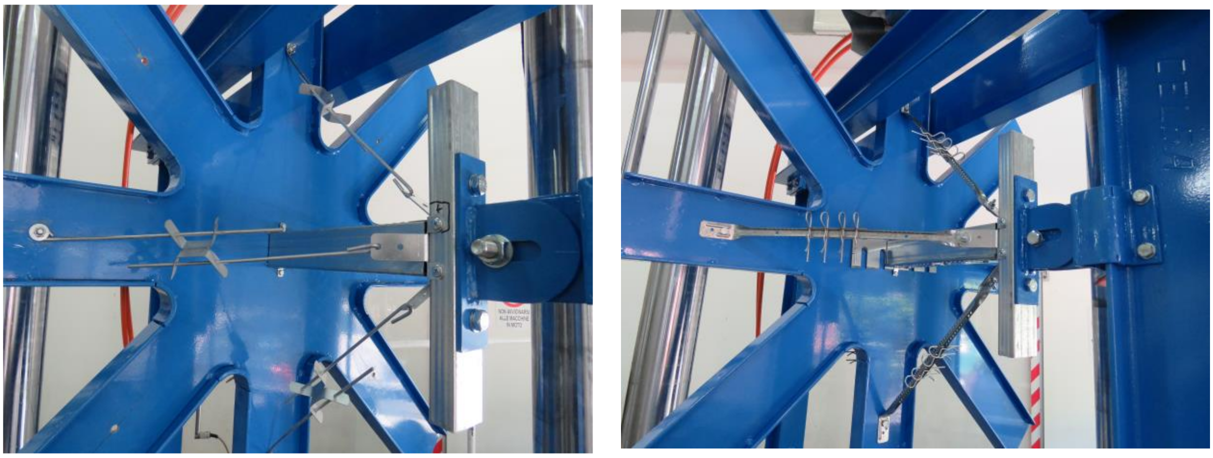


Figure 1: Unbraced lightweight suspended ceiling

2 INVESTIGATED BRACING SYSTEMS

To reduce the vulnerability of the lightweight suspended ceilings in high seismic zones, a bracing system could be designed according to the provisions of ASCE7-16 [9] and ASTM E-580 [10]. Many recent numerical and experimental studies in literature have shown the high seismic structural performance of steel members[11-34]. In the present work the experimental characterization of two different steel bracing system to improve the seismic performance of lightweight suspended ceilings is presented.

The investigated suspended ceilings components are made of four braces that are positioned diagonally with respect to the vertical rigid members that connect the ceiling to the above floor at specific points, both the braces and the vertical rigid element were connected to a CFS profile by means of a specially shaped connecting device. The two tested configurations differ in the type of diagonals used: i) flexible diagonal, ii) rigid diagonal. The characteristics of the two specimens are summarized in Figure 2.



a) Flexible bracing system b) Rigid bracing system

Figure 2. Investigated bracing system

3 EXPERIMENTAL CHARACTERIZATION

Cyclic tests on the bracing systems were performed with an universal testing machine. As can be depicted from Figure 3 a specially designed tests set-up was conceived, which allows to test the specimen taking into account the variability of the seismic action direction and due to the presence of sliding hinges, allowing to transfer only action parallel to the ceiling plane. During the test two samples were tested in parallel, so each bracing system is subjected to a load equal to half of the total load recorded by the machine. The cyclic testing method suggested in FEMA 461 [35], for examining the seismic behavior and failure mechanism of non-structural elements (i.e., lightweight suspended ceilings, partition walls) was adopted to perform a total number of 20 tests.

Figure 3. Quasi-static cyclic test

4 RESULTS

4.1 Cyclic response curve

Figure 4 shows the typical Force (*F*) against displacement (*d*) response curve derived from cyclic tests on rigid and flexible bracing system. The load and displacement were both monitored by the universal machine. The displacement is considered positive when an upward displacement is applied to the cross-shaped stiffened plate. Moreover, the force F is equivalent to half of the overall load recorded by the testing machine, and represents the load recorded for a single tested bracing system. From the response curve, as can be observed in Figure 4, the maximum resistance (F_p) and the elastic stiffness (K_e) can be computed in order to evaluate the structural response of the bracing system.

4.2 Damage phenomena

The collapse mechanisms observed for both the bracing system are localized in the connection between the braces and the specially shaped connecting device. In particular, for the rigid bracing system, the damages are related to the pull-out of the connecting screw and to the tearing of the connecting device; for the flexible bracing system the collapse is due to the loss of the hook connection between the braces and the connecting device (see Figure 5).

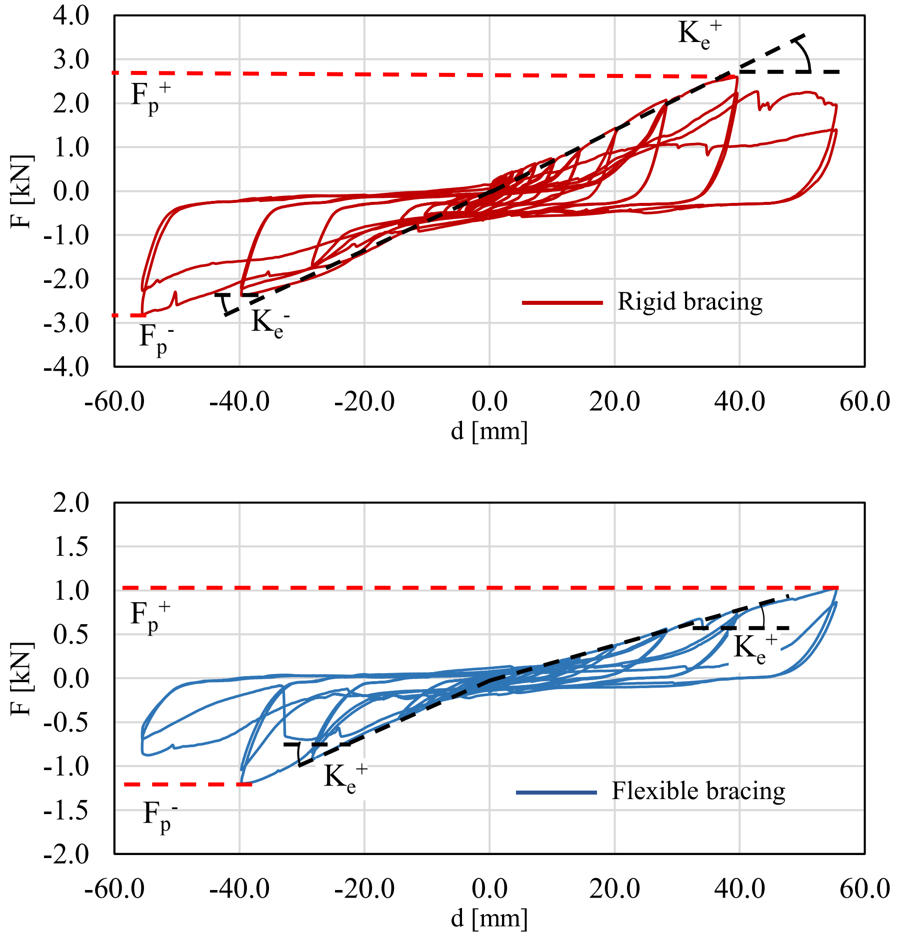


Figure 4. Cyclic responses: Force-displacement curves

Figure 5. Observed damage phenomena

5 COCNLUSION

A preliminary characterization of the seismic performance of two steel bracing system through quasi-static cyclic tests were presented.

The following conclusion for the component-level cyclic tests results can be drawn:

- The hysteretic behaviour was characterized by a strong pinching for both bracing systems;
- The collapse mechanism was due to damage concentrated in the connection between the bracing system and the CFS profile of the ceiling grid;

- The lateral strength of rigid bracing system was 2 times larger on average when compared with flexible braces;
- The lateral stiffness of rigid bracing system was 3 times larger on average when compared with flexible braces;
- Further shaking table tests could be performed to assess the seismic response of the investigated lightweight braced ceiling systems.

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