



# DREAMERS

**Design REsearch, implementation And Monitoring of Emerging technologies for a new generation of Resilient Steel buildings**

***Report with details able to ensure the integration between the structural and non-structural components***

## **Deliverable D1.1.2**

WP 1: Definitive design for the demonstration building

**Task 1.1: Architectural challenges and technological requirements**

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# Contents

|                                                                                                                                        |    |
|----------------------------------------------------------------------------------------------------------------------------------------|----|
| LIST OF FIGURES .....                                                                                                                  | 2  |
| LIST OF TABLES .....                                                                                                                   | 3  |
| 1. Introduction.....                                                                                                                   | 4  |
| 2. Lightweight steel drywall architectural systems .....                                                                               | 4  |
| 3. Lightweight steel drywall architectural systems under seismic actions.....                                                          | 5  |
| 4. Past research activities on the seismic performance evaluation of LWS<br>architectural non-structural systems funded by Knauf ..... | 7  |
| 5. Selection of LWS architectural non-structural systems .....                                                                         | 9  |
| 6. References.....                                                                                                                     | 12 |

## LIST OF FIGURES

|                                                                                                                                                                                                                                                |    |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| <i>Fig. 1: Typical application of LWS drywall interior partitions. a) Single stud partition; b) Double stud partition; c) Double stud partition</i>                                                                                            | 5  |
| <i>Fig. 2: Typical application of LWS drywall suspended ceilings. a) Suspended double level grid with C profile channels; b) Suspended flush profile grid with C profile channels; c) Suspended flush profile frame with special profiles.</i> | 5  |
| <i>Fig. 3: Typical application of LWS drywall façades. a) “Integrated” façade with single frame; b) “Integrated” façade with double frame; c) “Curtain” façade with double frame.</i>                                                          | 5  |
| <i>Fig. 4: Seismic mitigation details for LWS non-structural drywall products. a) Sliding connections for single stud partitions; b) Seismic bracing for suspended ceilings [4].</i>                                                           | 6  |
| <i>Fig. 5: a) Out-of-plane partition wall tests (tall partition wall); b) In-plane partition wall tests (Type 1 specimen); c) In-plane partition wall tests (Type 2 specimen).</i>                                                             | 8  |
| <i>Fig. 6: a) Shake-table tests on Type 1 prototype; b) Shake-table tests on Type 2 prototype.</i>                                                                                                                                             | 9  |
| <i>Fig. 7. Anti-seismic enhanced connection details for partitions.</i>                                                                                                                                                                        | 9  |
| <i>Fig. 8. Anti-seismic enhanced connection for façades</i>                                                                                                                                                                                    | 9  |
| <i>Fig. 9. Anti-seismic enhanced connection details adopted in ceilings</i>                                                                                                                                                                    | 10 |
| <i>Fig. 10. Fragility curves (IDR: interstory drift ratio).</i>                                                                                                                                                                                | 11 |

## LIST OF TABLES

|                                                                                        |           |
|----------------------------------------------------------------------------------------|-----------|
| <i>Tab 1. Probabilities of exceedance of the defined DSs for the Eurocode 8 limits</i> | <i>11</i> |
|----------------------------------------------------------------------------------------|-----------|

## 1. Introduction

This report summarizes the technical solutions for non-structural components (e.g. cladding, façade and ceilings) that comply with the requirements prescribed by the Italian law (NTC2018) and Eurocode 8, as described in Deliverable D1.2.

The general features of the examined technological details are first described. Afterwards, this document shows the solutions seismically conceived to obtain free from damage non-structural components for frequent earthquakes and almost no damage under severe earthquakes.

## 2. Lightweight steel drywall architectural systems

Typical applications of lightweight steel (LWS) products in non-structural architectural systems, as drywall non-load bearing partitions, suspended ceilings and façades are becoming more common and more available due to their big advantages respect to more traditional masonry-based solutions. Non-loadbearing LWS drywall partitions are mainly frames made of LWS profiles (usually 0.6 mm thick) pre-fabricated in C (studs) and U (tracks) cross-section formats. Stud profiles are generally installed with a spacing equal to a half width of the board cladding (about 600 mm). Usually, the cladding panels are gypsum boards screwed to the steel frame. Insulation material is inserted into the cavities between the cladding in order to achieve the expected safety and serviceability requirements related to no-structural performances, e.g the fire and acoustic performances (Figs. 1 a, b, c). The use of metal stud partitions allow to achieve high performances in terms of wall height (up to 12 m), sound insulation (up to 80 dB), fire protection (up to 120 minutes, fire resistance), and the seismic response can be fulfilled as well with very flexible and light solutions.

Different constructive options are available for drywall suspended ceilings, such as the use of a simple suspended furring channel, with a double profile frame or flush profile frame (Figs. 2 a, b, c). Generally, U and C cross-section LWS profiles and gypsum boards are used as basic products. With the use of universal brackets and single channel grids or flush profile frame a minimum suspension height of about 40 mm can be obtained, whereas the use of special connectors combined with a doubled profile frame allow a suspension height of several meters.

If adequate materials are selected, LWS drywall systems can be effectively and safely used for the envelope of the building. Indeed, the use of cement boards as exterior cladding and gypsum boards as interior cladding is normally recommended considering that the façade is exposed to moisture. Most common solutions of façade walls can be grouped in two main typologies: “Integrated” and “Curtain” walls (Figs. 3 a, b, c). “Integrated” façades can be made of single or double LWS frames. They are placed on the load-bearing slab and the surrounding perimeter connections are attached directly to the supporting frame. “Curtain” façades are made of a double LWS frame, in which only the interior frame is connected to the ceiling slab of the main structure. Usually, a specific thermal insulation material is applied in the wall cavity in order to guarantee the desired energetic performance. The exterior face of façade walls is generally cladded with cement boards and finished with glass fibre tape with an alkaline-resistant coating and cement-based plaster.

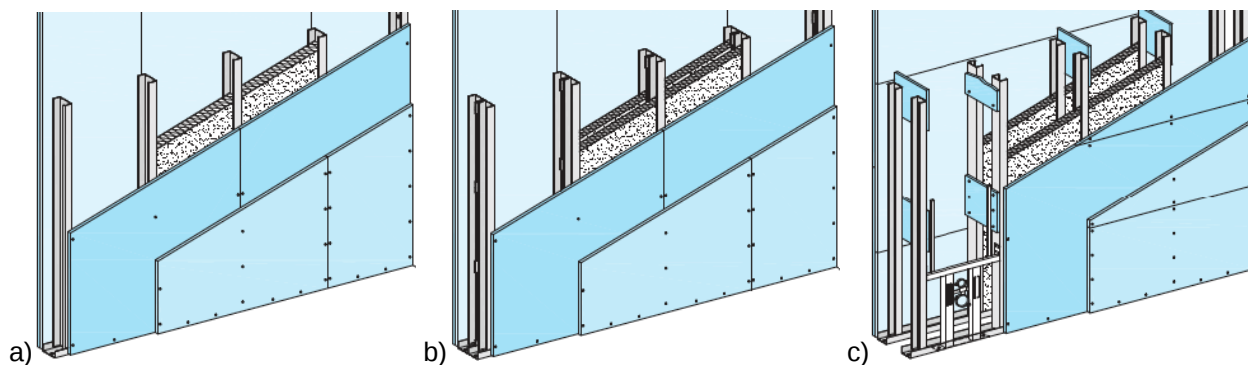


Fig. 1: Typical application of LWS drywall interior partitions. a) Single stud partition; b) Double stud partition; c) Double stud partition.

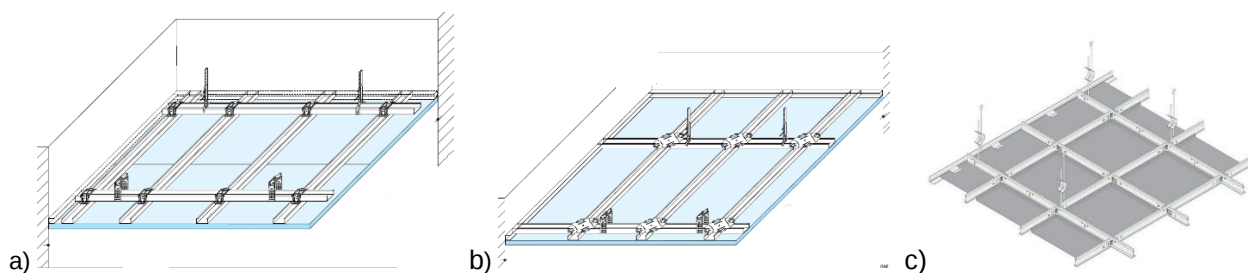


Fig. 2: Typical application of LWS drywall suspended ceilings. a) Suspended double level grid with C profile channels; b) Suspended flush profile grid with C profile channels; c) Suspended flush profile frame with special profiles.

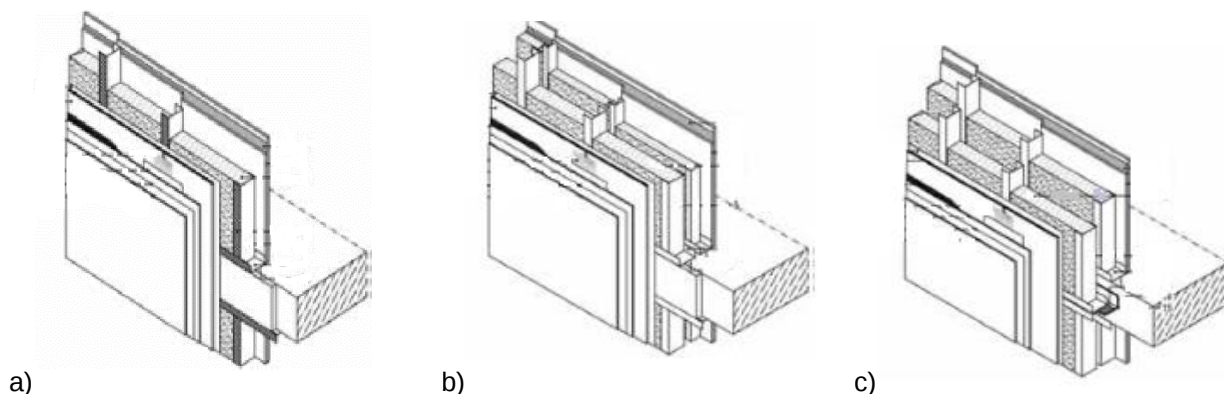
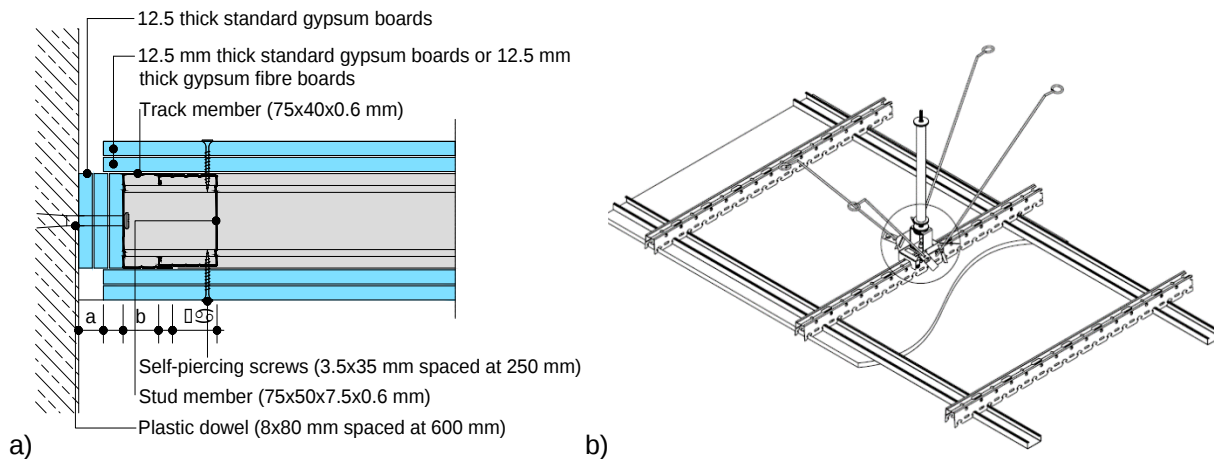


Fig. 3: Typical application of LWS drywall façades. a) "Integrated" façade with single frame; b) "Integrated" façade with double frame; c) "Curtain" façade with double frame.

### 3. Lightweight steel drywall architectural systems under seismic actions

Recent earthquakes in the most technologically advanced countries demonstrated the vulnerability of non-structural elements to relatively low seismic intensity levels and showed that their damage or collapse might have severe consequences in terms of economic, social and human life losses, even in the case in which no damage occurred in structural elements. In this framework, LWS drywall products can represent a valid alternative to traditional systems for non-structural architectural applications in seismic areas. In fact, LWS drywall products can guarantee a very good seismic response with respect to damage limit states, mainly thanks to their lightness and the possibility to easily improve their seismic response by means of relatively simple constructional details (Fig. 4).



*Fig. 4: Seismic mitigation details for LWS non-structural drywall products. a) Sliding connections for single stud partitions; b) Seismic bracing for suspended ceilings [4].*

However, since the prediction of the response of these systems under earthquake actions represents a complex issue, a large number of experimental research activities were addressed on this topic. These studies can be grouped in cyclic tests [Freeman 1977, Lee et al 2007, Restrepo & Bersofsky 2011, Retamales et al 2013, Tasligedik et al 2015, Petrone et al. 2015, Swensen et al 2016] and shake-table tests [Badillo-Almaraz et al 2007, Magliulo et al 2012] of partitions; shake-table tests of suspended ceilings [Badillo-Almaraz et al 2007, Magliulo et al 2012]; shake-table tests of systems made of partitions and suspended ceiling drywalls [Wang et al 2015, Jenkins 2015]. In addition, also specific activities for the experimental evaluation of mechanical properties of cladding boards [Petrone et al 2016] and stud-to-track connections [Rahmanishamsi & Soroushian 2016] were carried out.

From seismic building codes point of view, the first inclusion of the seismic prescriptions for non-structural components were in the 1967 Uniform Building Code [Uniform Building Code 1967] and followed the 1964 Alaska and 1971 San Fernando earthquakes. Subsequently, seismic design provisions were included in a wide variety of seismic codes covering a large number of non-structural components and systems, even if the prescriptions were focused only on the safety of critical equipment in essential facilities. Only in the last three decades, several guidelines and standards have developed more accurate seismic design provisions and evaluation procedures for non-structural components, in order to ensure proper performance during earthquakes.

Currently, the approach of the building codes, namely the European seismic code EN 1998-1 [CEN 2004], and the American codes for new buildings ASCE/SEI 7-10 [SEI/ASCE 2010] and for existing buildings ASCE/SEI 41-13 [SEI/ASCE 2013] regarding the design of non-structural systems follow three different paths.

The first code category is involved in providing prescriptive requirements for common products, such as suspended ceilings, by means of seismic protection details and specifications. The second code category assumes that the non-structural components should be designed for lateral seismic forces that are proportional to the element weight. In this regard, the equivalent lateral force method is used for acceleration-sensitive components, so that the anchorages and bracing systems should be able to withstand the earthquake accelerations. The third code category requires that the deformation-sensitive components should be designed to accommodate the design inter-storey drifts of the primary structure.

However, all of the above-mentioned standards and their prescribed approaches address the problem in a generic way, without providing any specific rules for non-structural components made with LWS. On the other hand, FEMA E-74 [FEMA 2011] is a practical guide towards reducing seismic

damages in different types of non-structural building components such as architectural, mechanical, electrical, plumbing, furniture fixtures, etc. In particular, Sections 6.3.2 and 6.3.4 provide guidelines for interior partition walls and ceilings, respectively by identifying various type of damages and proposing mitigation details for the components made with LWS. The report also provides connection details for partition walls in order to avoid connection of stud and sheathing to track and bracing details for the suspended ceiling systems.

#### **4. Past research activities on the seismic performance evaluation of LWS architectural non-structural systems funded by Knauf**

Recently, Knauf funded a research project focused on the seismic performance evaluation of LWS architectural non-structural systems, with a wide experimental campaign on partitions, façades and ceilings carried out at University of Naples Federico II [Fiorino et al 2018, Pali et al 2017, Fiorino et al 2019].

The research project had as main objective the experimental seismic characterization of LWS non-structural architectural building systems, consisting of partition walls, façades and ceilings. The activity was grouped into four different phases: ancillary tests, out-of-plane tests of partition walls, in-plane tests of partition walls and tests of subsystems.

The ancillary experimental activity included tests on steel materials, screws, panels and panel-to-steel connections, for a total of 144 tests.

The evaluation of out-of-plane response of partition walls involved full-scale out-of-plane quasi-static monotonic and dynamic identification tests (Fig. 5a) [Fiorino et al 2018]. The configurations of partition walls were selected in order to evaluate the influence of the following parameters: wall height (600 or 2700 mm); stud spacing (300 or 600 mm); connection between wall and surrounding element (fixed or sliding); gap between wall and surrounding element (20 or 30 mm for sliding connections); dowel type (plastic or steel); and dowel spacing (600 or 900 mm). In particular, sliding connections are an enhanced anti-seismic solution adopted in order to isolate the wall from the surrounding elements, whereas fixed connection is a common (basic) solution used in common practice. On the basis of these parameters, 15 series of specimens were defined, for a total number of 22 quasi-static monotonic and 11 dynamic identification tests. The experimental results showed that the initial response of the specimens was not influenced by the connection and dowel types, whereas the stiffness and strength, such as the wall dynamic response, depended mainly on the stud spacing.

The evaluation of the in-plane behaviour of partition walls involved full-scale in-plane quasi-static reversed cyclic tests carried out on two different typologies of specimens [Pali et al 2017]. The first typology (Type 1) is representative of partition walls surrounded by structural elements on all sides (Fig. 5b). The second typology (Type 2) is representative of partition walls surrounded by structural elements (e.g. floors or beams) at the top and bottom sides and connected with transverse façade walls (return walls) at their ends (Fig. 5c). For both cases, the partition walls were 2400 mm long and 2700 mm high. Different configurations of partition walls were selected in order to study the effect of different construction parameters: type of horizontal and vertical connections between indoor partition walls and surrounding elements (basic and enhanced anti-seismic connections); stud spacing; type of sheathing panels; type of joints finishing. Starting from the combination of the above defined parameters, 8 specimens for Type 1 and 4 specimens for Type 2 were tested. From the examination of test results, fragility curves were obtained. It was concluded that if no specifications are given on the connections between partition walls and surrounding elements, an inter-storey drift of 0.75% can be considered an adequate limit for damage limit states related with limited level of damage and required repair action (serviceability limit states), whereas if enhanced anti-seismic

connections are used (i.e. sliding-connection for Type 1 specimens), an acceptable limit of the inter-storey drift for serviceability limit states can be assumed equal to 1.00%.

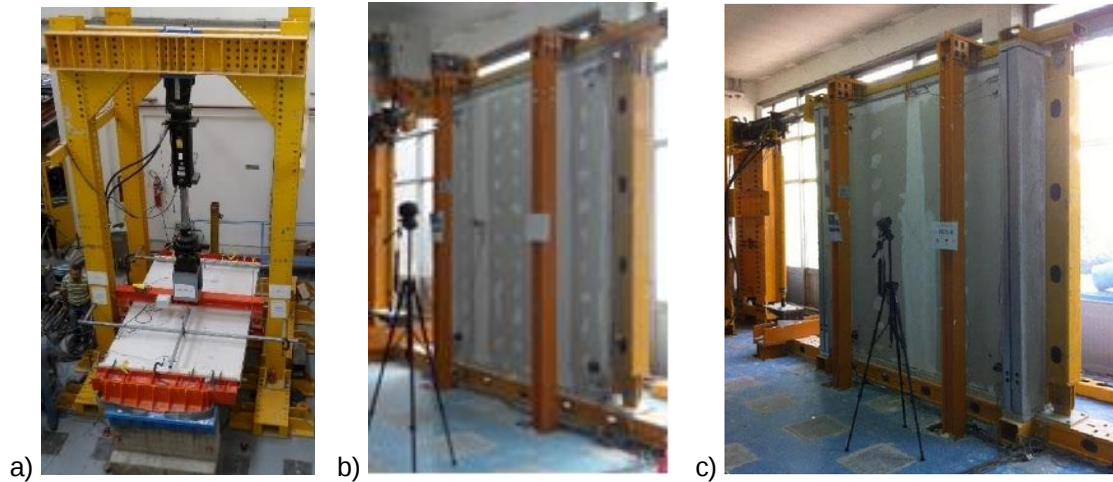


Fig. 5. a) Out-of-plane partition wall tests (tall partition wall); b) In-plane partition wall tests (Type 1 specimen); c) In-plane partition wall tests (Type 2 specimen).

The last phase of the experimental program involved shake-table tests of subsystems representative of partition walls, façade walls and ceilings. The set-up was a three-dimensional steel frame made of a bottom grid connected to the shaking-table and a top grid connected to a concrete block used to reproduce the mass of the system. The bottom and top grids were connected to each other by means of four uniaxial hinged columns. The lateral structural system of the steel frame, in the loading direction, was a special eccentric bracing system with pre-tensioned diagonals made of ultra-high strength steel. The tests were carried out on two different typologies of subsystems for a total number of five prototypes [Fiorino et al 2019]. Type 1 prototypes (Fig. 6a) were made of four partition walls infilled between test set-up columns, with dimension of 2400×2700 mm (length × height) in loading direction and 2200×2700 mm in the perpendicular direction. Type 2 prototypes (Fig. 6b) were a system consisting of façade walls of dimensions 2400×2700 mm in the loading direction and partition walls of dimensions 2300×2700 mm in the perpendicular to loading direction. The system was completed with a continuous suspended ceiling having a length of 1670 mm parallel to the loading direction and 2300 mm perpendicular to the loading direction. In this case too, for both Type 1 and Type 2 prototypes, basic and enhanced anti-seismic connections were tested. The earthquake input for the shake-table tests was an artificial time-history signal defined according to the ICBO-AC156 code, obtained by considering a spectral acceleration at short periods (SDS) equal to 1.0g. The input was scaled by a scaling factor from 5% to 120%. The main findings of this experimental activity showed that basic connections affected the response from the initial phases, providing an additional stiffness and strength, whereas the contribution of enhanced solutions is lower due the presence of an adequate gap in the sliding connections. In addition, the seismic response in terms of damage occurrence was also evaluated through fragility curves, which shows a certain amount of agreement to those obtained with previous in-plane quasi-static reversed cyclic tests on partition walls.

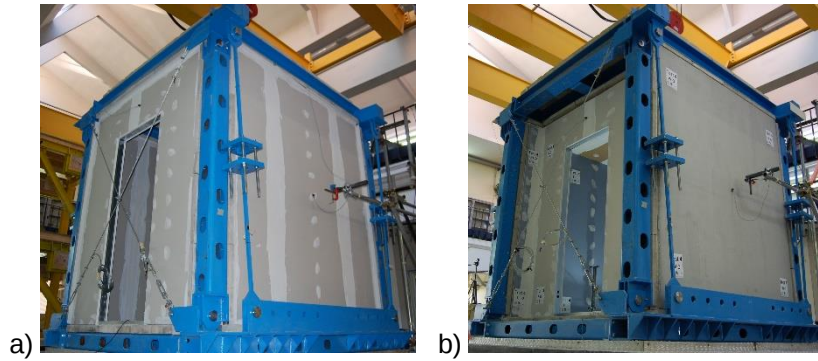


Fig. 6. a) Shake-table tests on Type 1 prototype; b) Shake-table tests on Type 2 prototype.

## 5. Selection of LWS architectural non-structural systems

The selection of LWS drywall products to guarantee a very good seismic response with respect to damage limit states has been made on the bases on results of past research activities on the seismic performance evaluation of LWS architectural non-structural systems funded by Knauf summarised in previous Section 4. For this reason, the so called anti-seismic enhanced solutions have been selected for non-load bearing partitions (Fig. 7), suspended ceilings (Fig. 8) and façades (Fig. 9).

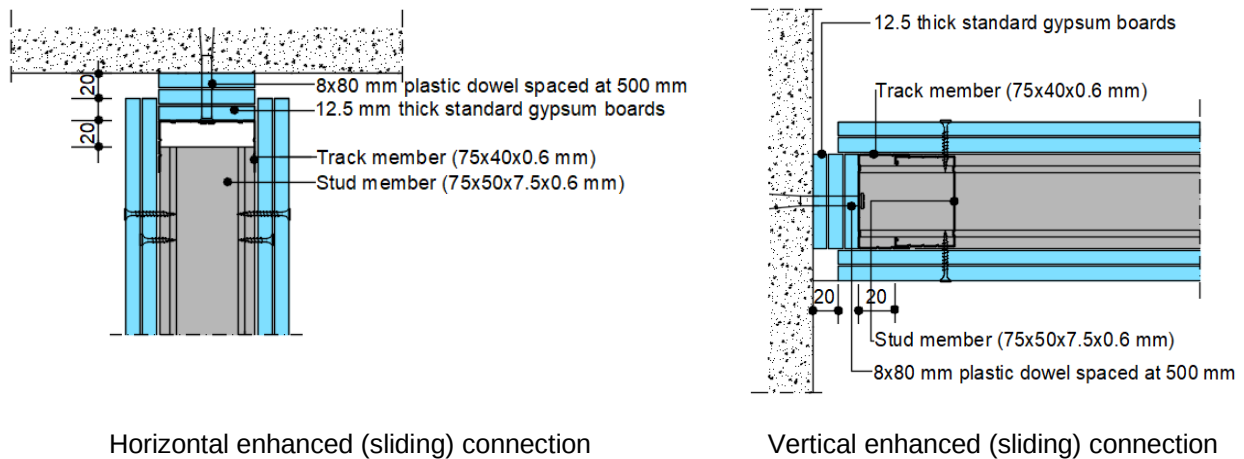


Fig. 7. Anti-seismic enhanced connection details for partitions.

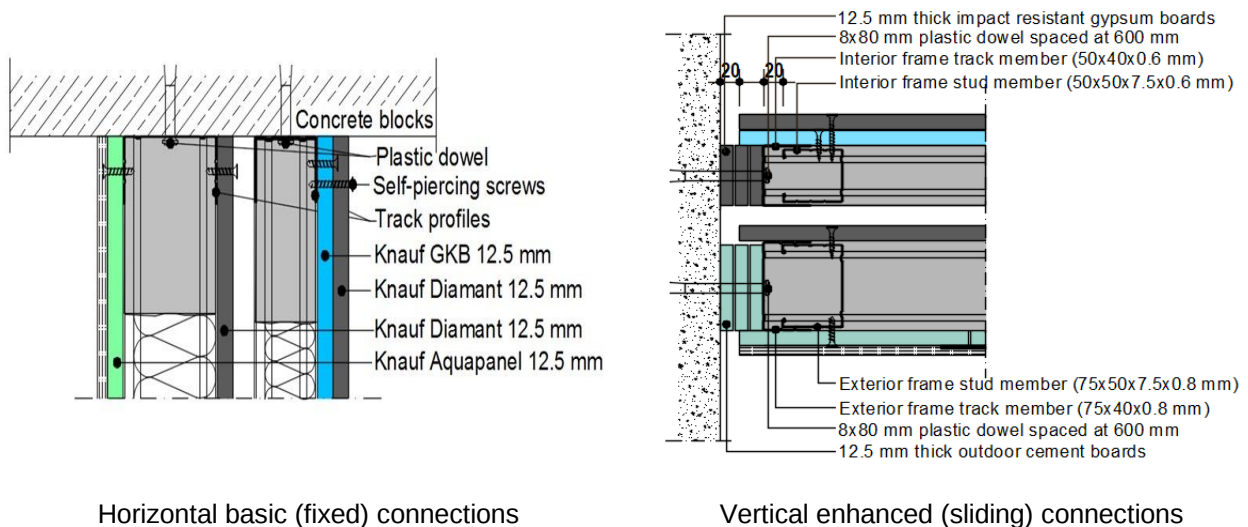


Fig. 8. Anti-seismic enhanced connection for façades.

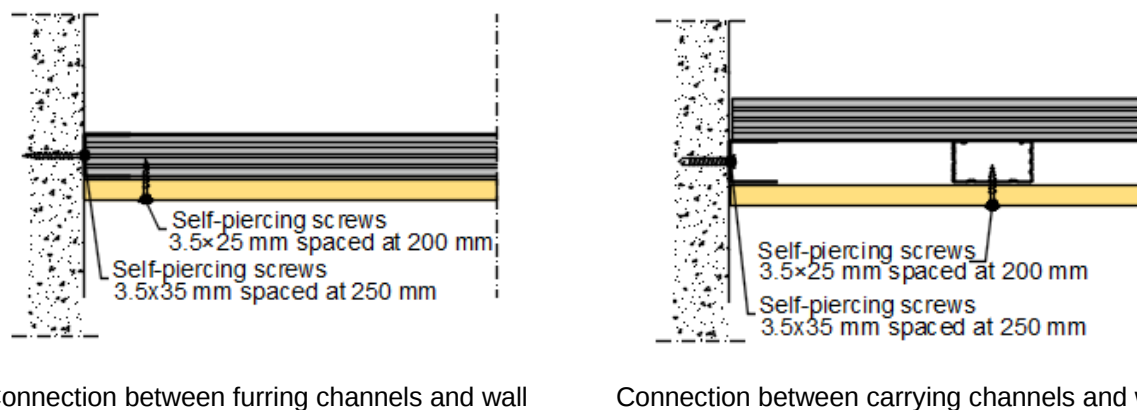


Fig. 9. Anti-seismic enhanced connection details adopted in ceilings

Based on the test results obtained within past research activities funded by Knauf and summarised in previous Section 4, the seismic fragility curves are available for selected partitions and façades. In particular, Figure 10 shows the fragility curves, together with the IDR limits given by Eurocode 8 Part 1 (dotted vertical lines), i.e. 0.75% for buildings having ductile non-structural components and 1.00% for buildings having ductile non-structural components fixed in a way so as not to interfere structural deformations.

In particular, the damage limit states (DSs) were defined according to the observed damage level and the required repair action as following: DS1 is characterized by superficial damage and it requires minimum repair with plaster, tape and paint; DS2 is characterized by local damage of sheathing boards and/or steel frame and it requires the replacement of few elements (boards and/or local repair of steel profiles); DS3 is characterized by severe damage and it requires the replacement of significant parts or whole non-structural component.

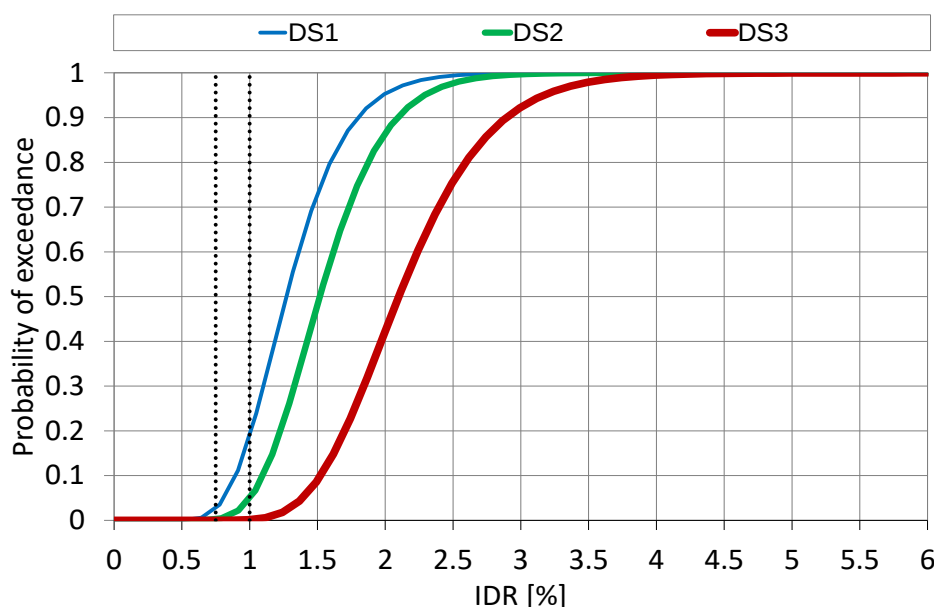


Fig. 10. Fragility curves (IDR: interstory drift ratio).

Furthermore, Table 1 shows for partitions and façades the probabilities of exceeding the defined DSs considering the interstory drift ratio (IDR) limits given by Eurocode 8 Part 1, i.e. 0.75% and 1.00%. Considering a reasonable limit for the probability of exceedance equal to 5%, it is possible to note that partitions and façades with enhanced connections exhibited low seismic fragility.

*Tab 1. Probabilities of exceedance of the defined DSs for the Eurocode 8 limits*

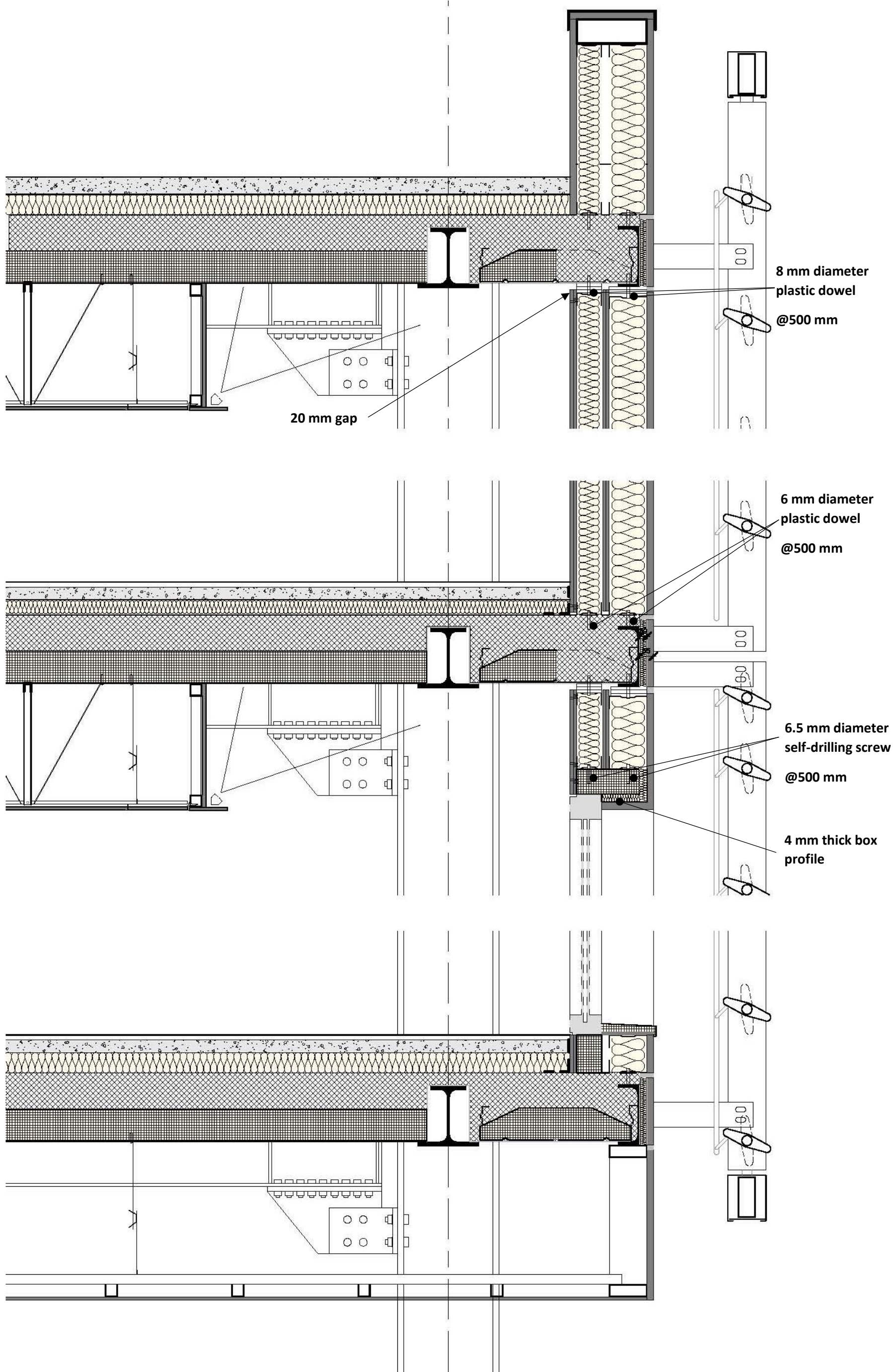
| <b>DS1</b>   |              | <b>DS2</b>   |              | <b>DS3</b>   |              |
|--------------|--------------|--------------|--------------|--------------|--------------|
| <b>0.75%</b> | <b>1.00%</b> | <b>0.75%</b> | <b>1.00%</b> | <b>0.75%</b> | <b>1.00%</b> |
| <b>0.03</b>  | 0.21         | <b>0.00</b>  | 0.07         | <b>0.00</b>  | <b>0.00</b>  |

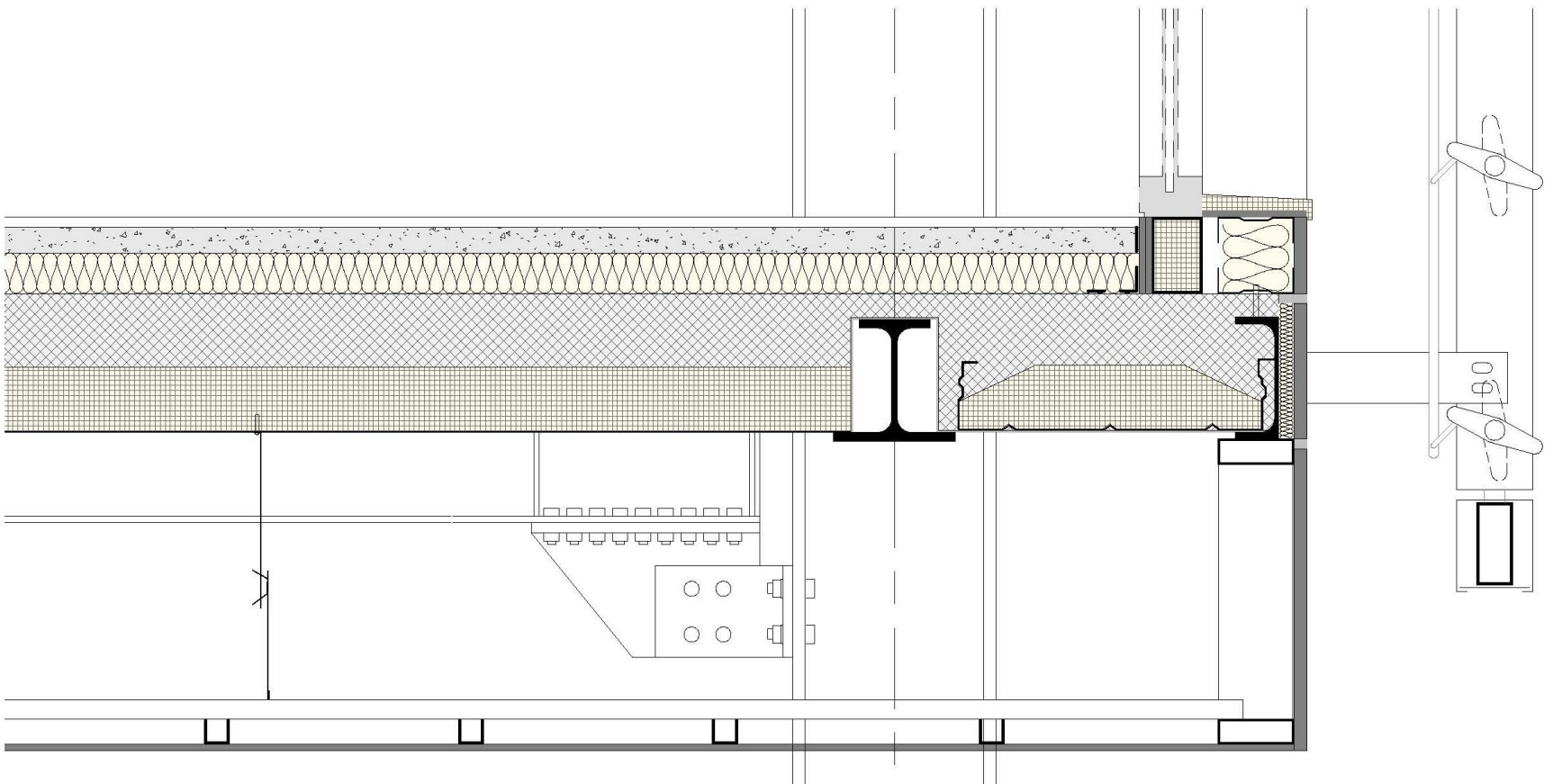
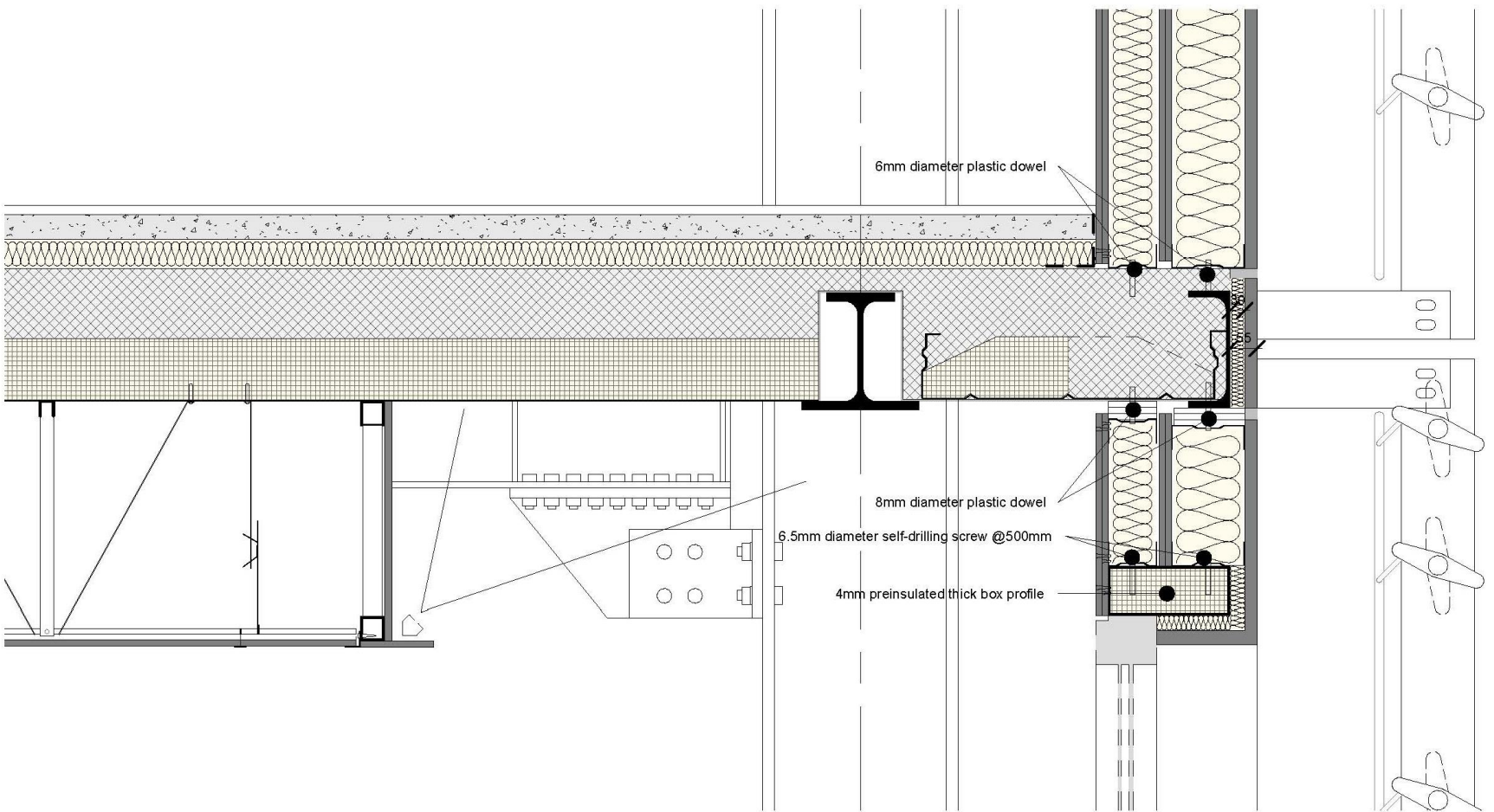
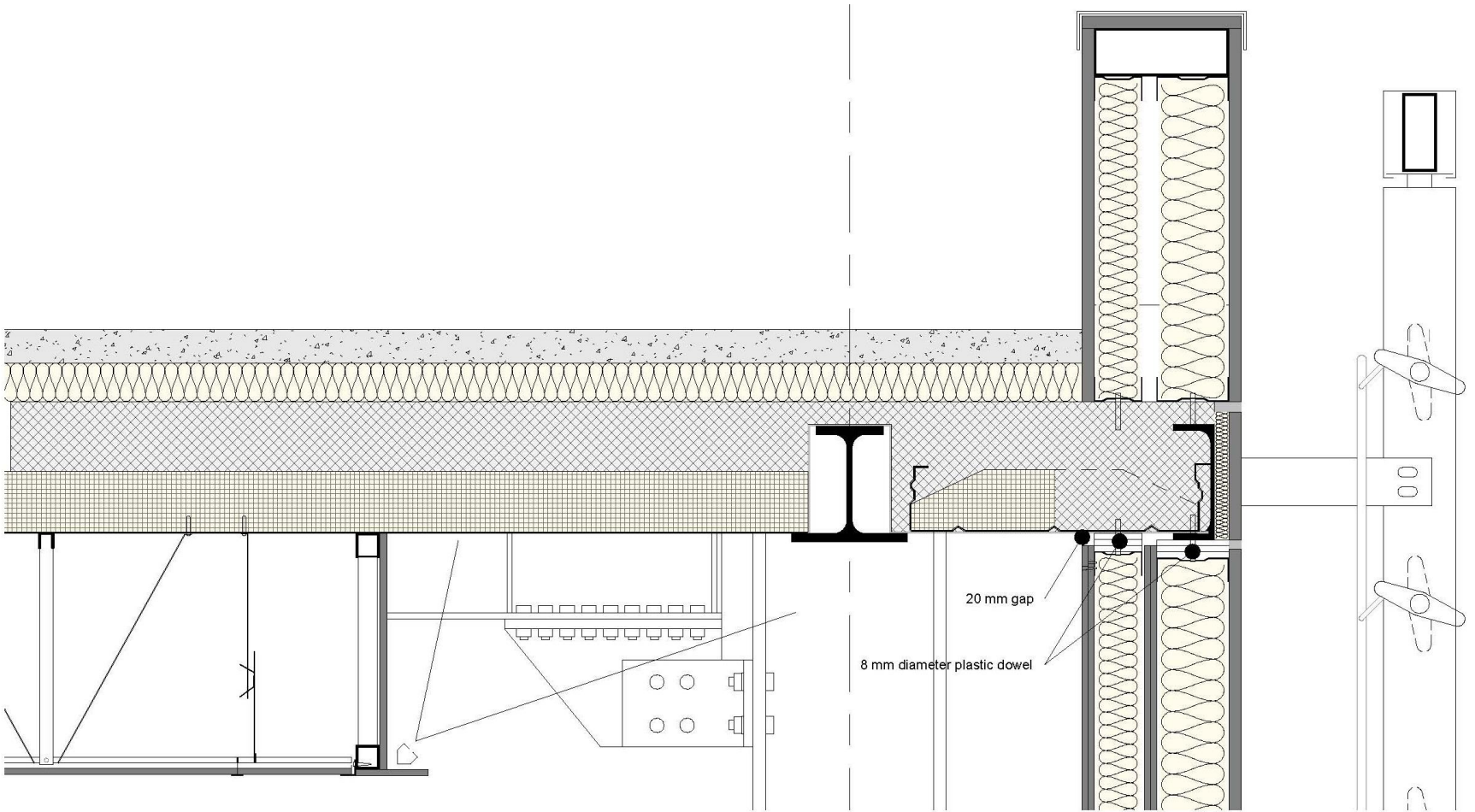
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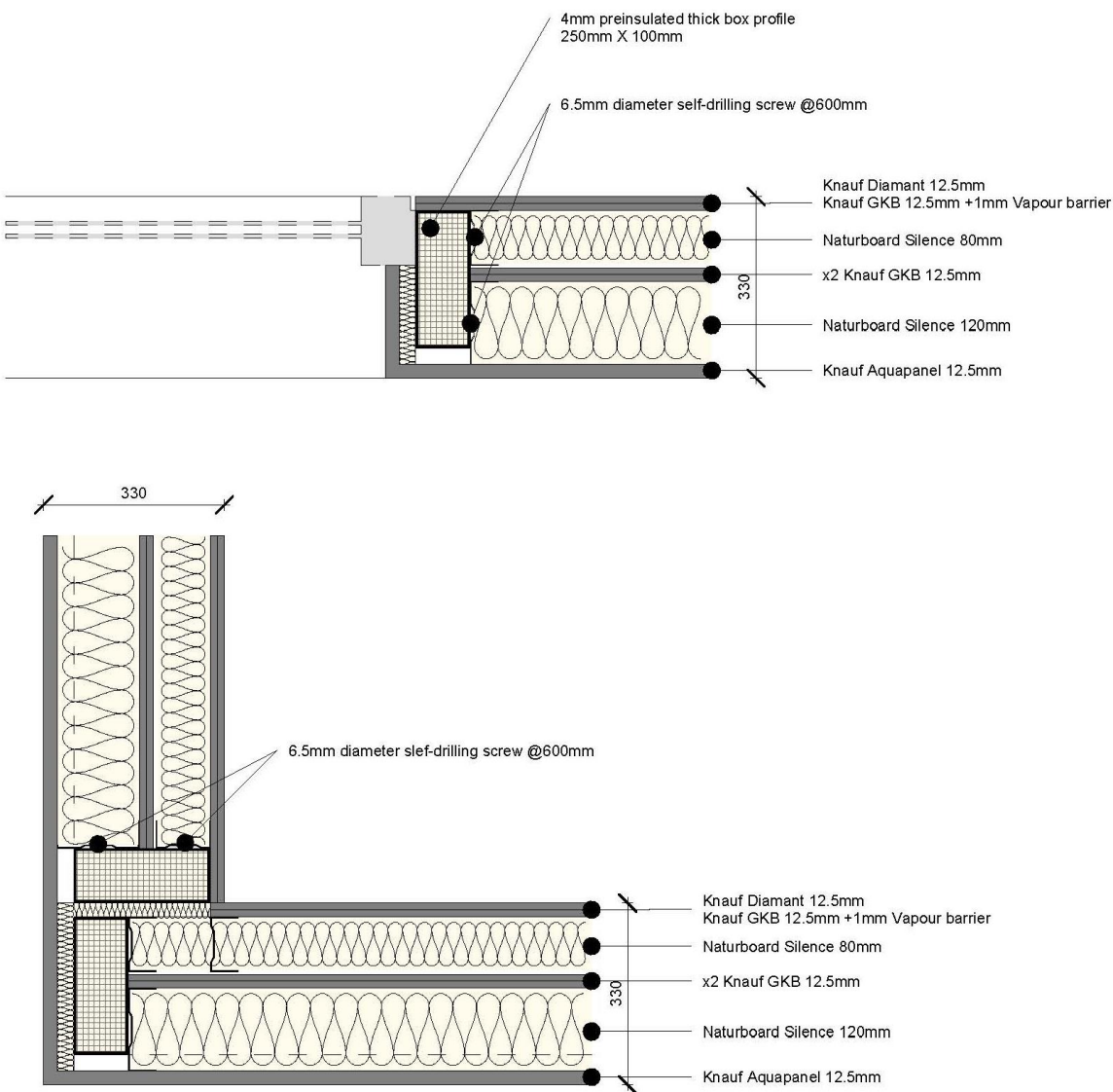
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FAÇADE – VERTICAL SECTION

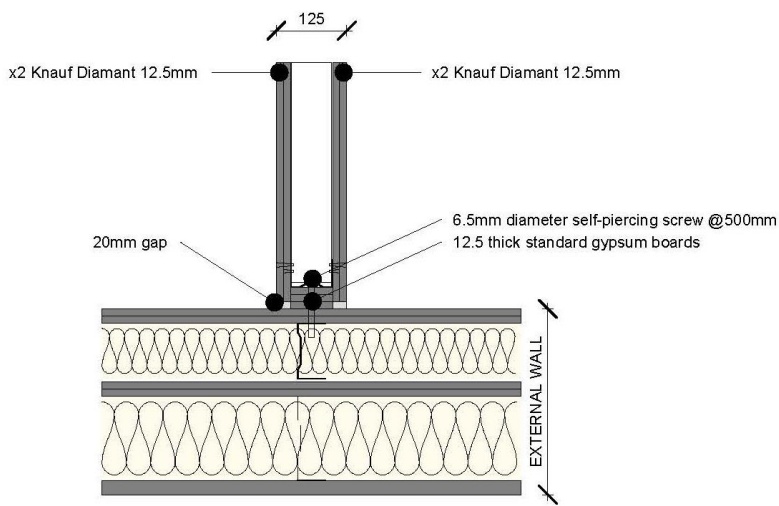




# FAÇADE – HORIZONTAL SECTIONS



# FAÇADE-TO-PARTITION – HORIZONTAL SECTIONS



PARTITION – VERTICAL SECTIONS

