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Robustness and resilience of a passive control solution assembling buffer and cladding panels

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Abstract. The adoption of cladding panels as dissipation device is a sort of passive control "ante litteram" for residential and commercial buildings. This paper gives details on the current technology outlining the difference between buffer panels and cladding panels. The discussion of robustness and resilience of the resulting system is afforded. It is shown that the strength of such solution, originally related to economy and light weight, is mainly associated with the respect of the main robustness requisites, as well as the short time it requires for removal and replacement (resilience).

Keywords: buffer panels; cladding panels; passive structural control; resilience; robustness

1. Introduction

In 1976, just after the earthquake in Friuli, Italy, professor Grandori, the father of Italian seismic engineering, designed an energy dissipation device inspired by the shape of the metallic motorway guard rails in use at that time. The device would have found room in the buffer and/or cladding panels to be mounted on the structural skeleton of residential and commercial buildings. An overlook of the idea is part of the preface of reference (Grandori *et al.* 2001).

Early work on structural control using cladding panels includes double-layer foam cladding (Ma and Ye 2007), tube-core cladding (Theobald and Nurick 2010), and sacrificial panels composed of foam-based materials (Wu *et al*. 2010, Shim *et al.* 2012, Merrett *et al.* 2013), all geared towards mitigation of blast loads. A considerable challenge with these panels is their low performance versus low-frequency loads and their relatively high costs. Energy dissipation through cladding connections have also been considered. Goodno *et al*. (1992) studied ductile connections to dissipate energy through plastic deformations and therefore reduce inter-story drift. Baird *et al.* [8] explored a U-shaped flexural plate connection to passively dissipate seismic energy. Mannetes and Mermari (2014) reviewed utilizations of cladding panel systems as energy dissipation devices for seismic loads. Amadio and Bedon (2012) proposed a viscoelastic spider connection for mitigating blast loads. All of the surveyed energy dissipation mechanisms based on cladding panels or connections are passive dissipation strategies.

Focusing attention on multistory buildings, one clearly detects three components: the structural skeleton, either in steel or in reinforced concrete; the elements to which one delegates the thermal, acoustic and moisture insulation of the internal areas, i.e., the buffer panels; last, but not the least, the elements delegated to reduce the light aggression and to ameliorate the esthetic rendering from outside, i.e., the cladding panels.

After decades characterized by the local assemblage of buffer panels by bricks (resulting in rather dangerous collapse modes due to seismic and other catastrophic events), fifty years ago, industrially assembled buffer panels started to be successful in architecture. Their drawback was that they were designed to be self-supporting, but only self-supporting, i.e., there was no way to mount on them cladding panels, mainly if made by crystal glass or brick tiles.

A technology to bypass this limitation is considered in this paper. A part its economic convenience, it is shown how robustness and resilience are its fascinating perspective.

2. Buffer panels and cladding panels

A starting buffer panel is actually a sandwich panel with two external sheets in aluminium or steel of thickness 0.4-0.6 mm. A thermal and acoustic isolation material fills the inter-sheets space. Some alternative solutions are summarized in Table 1. The panel is sutured along the perimeter by A.B.S. (acrylonitrile, butadiene, and styrene combine to form this common plastic) sheaths.

Thermal insulation materials are specifically designed to reduce the heat flow by limiting heat conduction, convection, radiation or all three while performing one or more of the following functions:

- Conserving energy by reducing heat loss or gain;
- Controlling surface temperatures for personnel protection and comfort;

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- Facilitating vapour flow and water condensation of a process;
- Increasing operating efficiency of heating/ventilating/cooling, plumbing, steam, process and power systems found in commercial and industrial installations.

There are three general material types into which thermal insulation materials can be categorized.

1. **Fibrous Insulations:** Fibrous insulations are composed of small diameter fibres which finely divide the air space. The fibres may be perpendicular or parallel to the surface being insulated, and they may or may not be bonded together. Silica, glass, rock wool, slag wool and alumina silica fibres are used. The most widely used insulations of this type are glass fibre and mineral wool.
2. **Cellular Insulations:** Cellular insulations contain small individual cells separated from each other. The cellular material may be glass or foamed plastic such as polystyrene (closed cell), polyurethane, polyisocyanurate, polyolefin, or elastomer.
3. **Granular Insulations:** Granular insulations have small nodules which contain voids or hollows. These are not considered true cellular materials since gas can be transferred between the individual spaces. This type may be produced as a loose or pourable material, or combined with a binder and fibres to make a rigid insulation. Examples of these insulations are calcium silicate, expanded vermiculite, perlite, cellulose, diatomaceous earth and expanded polystyrene.

From the acoustic insulation point of view, porous materials permeable to the air must be used for filling interspaces. The cellular insulation materials normally used in thermal insulation, which have closed cells, are not suitable. In some cases, they can even worsen the acoustic performance of the layer configuration. For best results, the interspace thickness should be totally filled with fibrous insulating materials.

The sandwich panel is designed to be self-supporting. Thus, no cladding panel can be superposed. The Trewall system, as discussed in this paper, inserts a lamellar wood vertical beam every 500 or 1000 mm. The beam cross section is rectangular, the basis being 100 mm and the height spanning from 140 to 200 mm (see Fig. 1).

Table 1 Filling insulation materials and physical properties.

Category	Material	Range of application °C	Thermal conductivity W/(m K) at 25°C
Fibre insulation	Glass fibre	-40/+535	0.033
	Glass wool	-195/+230	0.04
	Mineral wool	0/+760	0.045
Cellular insulation	Polyurethane (PUR) foam	-210/+120	0.028
Lamellar wood	-	-	0.13

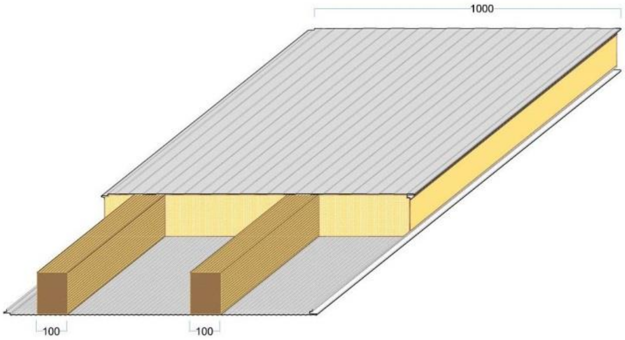

Fig. 1 Geometric features of the buffer panel

Fig. 2 Blind metal skeleton covering the façade

Alternative beam sections, also made by two coupled thin rectangular beams, were also introduced to promote corrugated external sheet shapes.

The added wood beams are the anchorage of vertical metallic elements supporting ribbed staves connected by a seaming system, so that the façade is covered by a blind metal skeleton (Fig. 2) able to support cladding panels in glass, plastic or even brick tiles.

It is worth noticing that the cost of such a panel system is evaluated to be 60% of traditional brick buffers. Even its lightness is much more convenient.

3. Connecting schemes

The vertical metal elements of the blind skeleton are fixed to the buffer panels having care that any screw deeply enters the wood beam.

Possible connections of the buffer panels with the building skeleton are roughly sketched in Fig. 3.

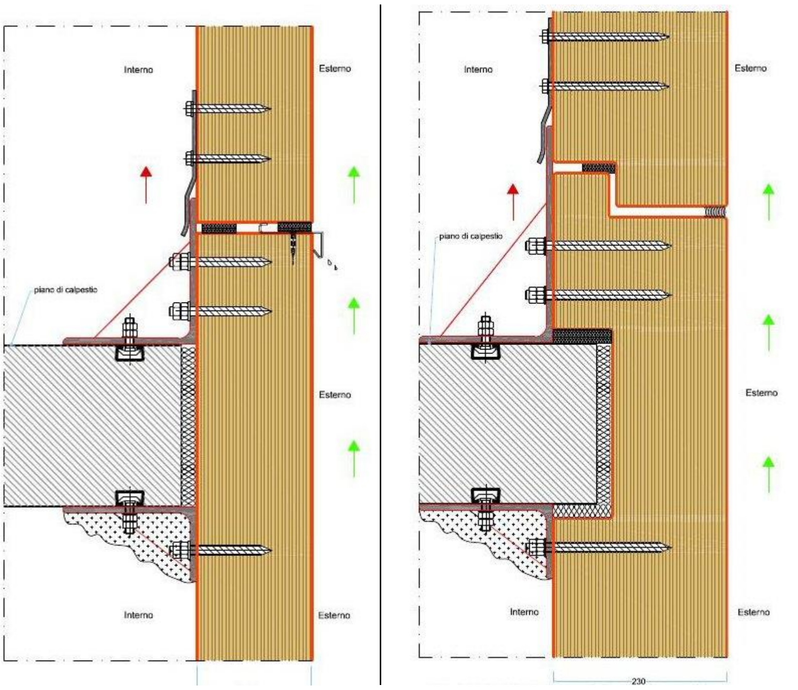

Fig. 3 Mounting two different types of buffer panels

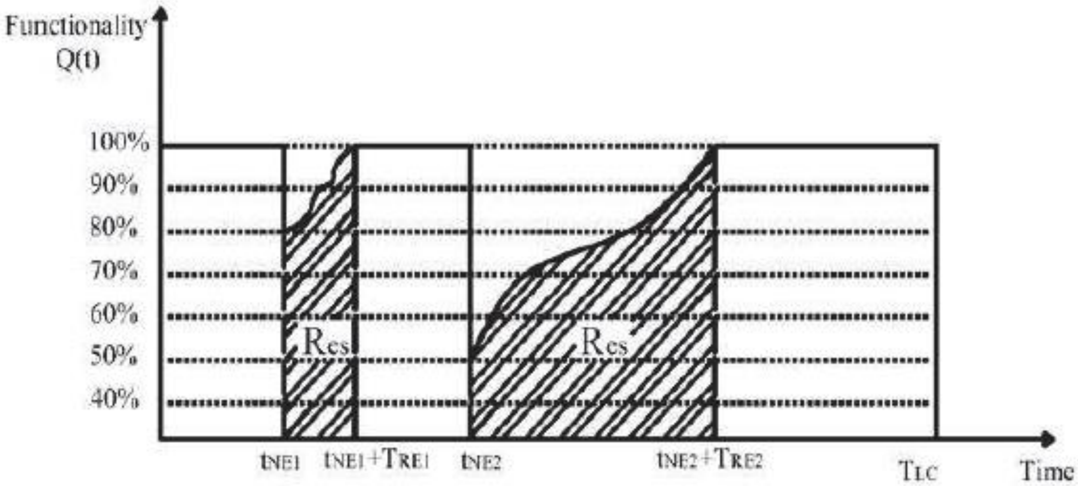

Fig. 4 Introducing the concept of resilience

The schemes in Fig. 3 can be regarded as the first technological approach for appending the buffer panels. It was soon realized that in seismic areas it would have been convenient to introduce sliding links with the double function of avoiding local failure and promoting energy dissipation. Several solutions were tested and implemented, ranging from the use of rubber supports to the adoption of rails.

In this aseismic role, the panel comes with slide stops allowing horizontal misalignments up to a few centimetres. Of course this sliding limit is a design variables to be harmonized with local seismicity information.

4. Robustness and resilience

When a panel façade is considered, the Ronan Point accident is still a main issue. The accident occurred at a 21-storey tower block. It partly collapsed on 16 May 1968, only two months after it had opened. A gas explosion blew out some load-bearing walls, causing the collapse of one entire corner of the building (which killed four people and injured 17). The panel system discussed in the previous section couples two levels of sewing: the wood skeleton inside the panel and the metal skeleton external to the panel. Thus a local failure is prevented from propagating and progressive failure is avoided.

Eugene P. Odum, biologist and pioneer in studying ecosystems, introduced the concept of resilience as the ability of a system to recover when modified by a perturbation. On one side one has the system functionality and on the other side the progressing time (Fig. 4).

As sketched in Fig. 4, the resilience depends on the value of the outlined areas after critical events. The target is to have it as close as possible to the full functionality. The panel system discussed in the previous section just requires an inspection to detect local failure and the replacement of the damaged elements. If modular panels are adopted and some of them are stored in the building basement, both the operations are easily developed by days, rather than months as generally required.

5. Potential of the cladding system

The monumental cultural heritage of many countries, from the Mediterranean Sea to the Baltic Sea, from the British islands to the Flanders, was built in bricks. When the location is prone to seismic events, bricks are involved in collapse modes which often are catastrophic for the structural system and the occupants.

The external surface of the panels can be replaced by brick-like elements so that collapsed walls can be easily replaced by elements of lower mass, while retaining the aesthetic features of the façade.

In other words, robustness and resilience are transferred by the cladding panel technology to masonry systems, which usually do not show such desirable attributes.

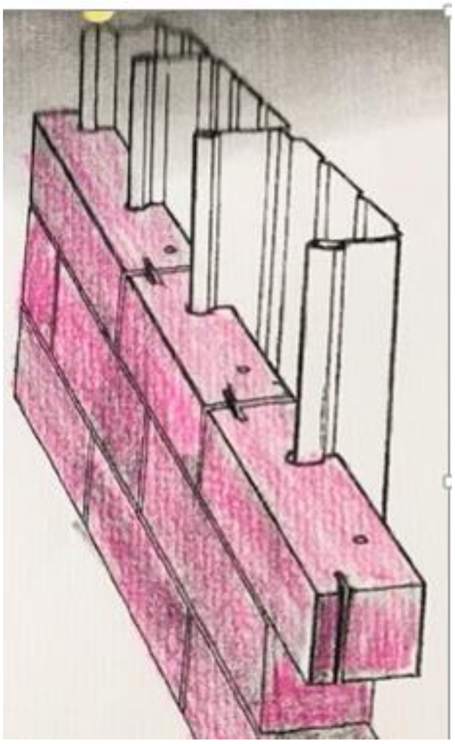

Fig. 5 Conceiving a cladding panel with brick features

6. Conclusions

This paper focuses attention on cladding panels made by metallic (or plastic) covers, over an isolating sacrificial material reinforced by wood ribs. The main technical advantages are discussed in terms of thermal and acoustic isolation, fully sustainable (green) production, mounting and demolition cycles, environment soft material selection and cheap cost of the single assembled panel.

It is shown that the main advantages of such a solution relies on its robustness and its resilience.

Acknowledgments

The achievements reported in this manuscript are the developments pursued on the field since the trenchant idea firstly utilized during the construction of the new Milan airport Malpensa 2000.

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