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Low-Rise 3D Panel Structures for Hot Regions: Design Guidelines and Case Studies

Abstract More than 40 years ago, lightweight composite panels fabricated from polystyrene, steel, and shotcrete concrete were used to construct non-load-bearing walls such as partition walls and façade cladding. Recently, many private companies all over the world have started manufacturing these panels commercially to be used as load-bearing walls or floor slabs in the construction of low-rise structures up to three stories high by proposing a new building system called a “3D panel building system.” The light weight of these panels, along with the fact that they are easy to handle, enhance the speed of construction, offer good heat insulation properties, and they cost less by avoiding the need for either formwork or skilled workers, make it an acceptable construction practice. Tests reported in the literature indicate that the degree of heat insulation of a 3D panel wall significantly exceeds that of partitions or curtain walls obtained with the traditional systems. This produces energy savings equal to 40% with both heating and cooling, making these panels suitable for construction in hot regions and especially in rural areas. In the literature, there are several reports of experimental works conducted by the author and by many researchers worldwide in an effort to determine the mechanical properties of the panels and to investigate the efficiency of its building system in terms of resistance to gravity and seismic loads. However, there is not enough information on their design rules. In this paper, some design guidelines are proposed. The guidelines rely on experimental findings and on reinforced concrete (RC) design building codes such as ACI-318 [Building Code Requirements for Reinforced Concrete (ACI 318-95), American Concrete Institute] and UBC. Two design case studies in Turkey using the proposed guidelines are presented. The first case is the design of a small 3D panel house and the second case is the design of a 3D panel factory. The proposed design rules are conservative and follow the rules specified for designing reinforced concrete structures with some modifications.

Keywords 3D panel - Shotcrete concrete - Design - Seismic - Hot region
Introduction

Construction of buildings with good heat insulation in hot regions is needed, especially in rural areas. In past decades, clay masonry buildings were commonly used in hot, rural areas. These buildings have good heat insulation properties. However, during even a moderate earthquake they suffer heavy damage because of their heavy mass and low-strength materials. Nowadays, reinforced concrete (RC) buildings are starting to be constructed in hot, rural areas as a modern style of building. However, they are expensive because of their need for heat insulation panels and because of the high cost of transporting construction machines and materials to the job site in rural areas. Hence, modern style and low-cost buildings with adequate strength and good heat insulation properties are needed in hot, rural areas. In the early 1970s, lightweight panels with good heat insulation properties fabricated from polystyrene, steel, and shotcrete concrete were used in the United States and Canada to construct nonload-bearing walls such as partition walls and façade cladding [1]. Recently, some manufacturing companies worldwide have proposed using these panels as structural elements of a new building system called a “3D panel building system” to construct low-rise structures up to three stories high. Each panel consists of a welded wire space truss integrated with a polystyrene core sheet, with shotcrete concrete applied from both sides of the polystyrene sheet to convert the panel to a structural wall. A general view and cross-sectional details of the 3D panel is given in Fig. 1. The 3D panel system construction technique is not new, since it had been proposed in the United States in the 1990s and in some European countries in the first years of the new century. It seemed to be interesting due to its reduced weight, high construction speed, and reduced costs by avoiding formworks and the need for skilled workers. But in spite of these features, it did not take hold as the manufacturers hoped. The reason was probably because the low quality of the structures built using this technique was considered unacceptable in the United States and, moreover, in Europe, violating some code provisions. Nevertheless, the technique could be of some interest in other countries where environmental regulations and building standards are rather different from the western countries.

The wall panel receives its strength and rigidity from the diagonal cross wires welded to the wire fabric on each side. This combination produces a truss behavior, which provides rigidity and shear terms for a full composite behavior [2]. The value of the total heat transmittance of a 3D panel wall with polystyrene sheet thickness of 40 mm (density 15 kg/m³) and applied with shotcrete concrete with thickness of 30 mm on both sides, is equal to 0.78 W/m² K [2]. Such a degree of heat insulation exceeds that of the partitions or curtain walls obtained with the traditional systems, producing energy savings equal to 40% with both heating and cooling, which makes these panel buildings suitable for construction in hot regions. The 3D panels are architect-friendly because they can easily take any architectural shape such as arches, domes, and stairs. In Turkey, more than 200 structures have been built using the 3D panel building system, including two- and three-story houses, three-story office buildings, small mosques, roofs, and one-story factory buildings. Figure 2 shows some of these applications. The manufacturing cost of the 3D panels in Turkey is a bit high because of the high cost of the electric energy used during manufacturing process (leading to high electric bills), which is why the 3D panel system saves only 20% of the construction cost compared with reinforced concrete structures. The cost savings is mainly due to the fact that there is no need for formworks, fewer laborers are needed, and