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Structural behavior of axially loaded precast foamed concrete sandwich panels

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HIGHLIGHTS

- FC has a distinctive property of being able to maintain strength to weight ratio characteristic.
- Six PFCSPs varying in height were tested to determine the ultimate axial load till failure.
- The increase in *H*/*t* from 14 to 24 is decreased by 26.3% on the ultimate strength of PFCSPs.
- A semi-empirical equation is proposed to accurately fit the experimental and analytical studies approach.

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ABSTRACT

This paper presents results from an experimental and analytical study of precast foamed concrete sandwich panels (PFCSPs). Full-scale experimental tests of six PFCSPs were conducted to study the behavior of the panels under axial loads. Foamed concrete (FC) was used to cast PFCSP concrete wythes. The axial load-bearing capacity, load–deflection profiles, load–strain relationships, slenderness ratio, load–displacement, load–deformation, failure and collapse modes, cracking patterns, and propagations under constant increments of axial loads were recorded and discussed. The properties and use of FC were briefly reviewed. Results of the experimental test and finite element analysis were compared with the theoretical values calculated based on the American Concrete Institute (ACI) design equation for a solid concrete wall and other empirical formulas developed by antecedent researchers which might be applicable to predict the ultimate load-bearing capacity of sandwich panels. A semi-empirical formula was proposed based on the laboratory test and finite element analysis results.

1. Introduction

Prior to 1960, sandwich technology was confined entirely to aerospace applications. An increase in the number of alternative uses of this technology was discovered when structural insulated panels (SIP) were used to construct buildings, refrigerated storages, and automobiles and in various processes operations in the shipbuilding industries [1]. In the early age of precast SIP, panels were manufactured as a non-load-bearing building system called cladding panel, which consists of two thick internal and external concrete layers, also referred to as wythes [2]. Precast concrete sandwich panels (PCSPs) were accepted as a practical building system for more than 50 years in North America [3]. However, the first use of these panels could not be determined by the Precast/Prestressed Concrete Institute (PCI) committee [4]. From the design point of view, concrete wythes were designed as load-bearing and non-load-bearing structures for the external and internal wythes respectively, and the two layers were separated by insulation materials [5]. The structural behavior of PCSP depends on the strength and stiffness of the mechanical shear connector. To meet the strength and stiffness requirements, the shear connector must possess sufficient strength that will result in a composite action, thereby allowing adequate shear transfer and full composite behavior between the concrete wythes [6]. The capability of panel composite behavior decreases over time and is not maintained, and it depends significantly on the shear connector strength over the lifespan of the panel [7].

A continuous steel truss-shaped shear connector is the most effective shear connector used to attach concrete wythes together because it allows a full transfer of shear forces resulting from the bending between them. Thermal behavior is governed by the value of insulation provided, and panel buckling is restricted by the strength of both concrete wythes [8–10]. A typical shear connector

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is depicted in Fig. 1. The interaction between the inner and outer concrete wythes can determine the structural behavior of PCSP components while trying to maintain insulation in place. PCSPs became widely used as an appropriate system to construct structural shell applications for all building types. This prototype of composite sandwich panel applications was later developed and manufactured [5,11–14]. Besides, different kinds of shear connection can also be used to manufacture composite sandwich panels. In particular, Gara et al. [14] used horizontal steel connectors to integrate the connection means of sandwich wall panels so that it obtained a semi-composite behavior. Abdelghani [15] used a continuous steel truss shear connectors to hold the concrete wythes of PCSP, hence, the investigation results were shown a partial composite action, specifically at ultimate stage, but this type of shear connector was reported the most structurally efficient used. Einea [12] proposed several hybrid truss shear connectors classified into two types; composite and non-composite shear connectors. Thus, these types of shear connector have been given a semi-composite behavior but enhanced the thermal performance due to the high control achieved by the design material (e.g. fiber reinforced plastic bars). Also, Bush et al. [8] used truss girder shear connectors oriented in the longitudinal direction so that the results were also presented a partial composite behavior.

The valuable functions of PCSPs are highly similar to those of precast solid wall panels, and they differ only in their buildups. An interest in sandwich panels as bearing wall has been recently observed, leading manufacturers to search for sufficient viable products. Engineers/architects and researchers are pleased with the structural efficacy, insulation efficiency, and energy performance of wall/slab sandwich panels [4,5,15–18]. The PCSP design first functioned as a structurally energy-efficient system. PCSP was advanced for use as a wall bearing because of its capacity to withstand loads that act from the roof or floor of the building elements and to transfer these loads directly to the foundation [10].

Moreover, the beneficial features of PCSP walls include high quality control, fast erection, proven durability, low maintenance cost, and attractive architectural appearance. These beneficial features were deemed as unique characteristics and were developed to improve the current system components of buildings and constructions [3,4,19]. The complex behavior of PCSP due to its material non-linearity, the uncertain role of the shear connectors and the interaction between various components has led researchers to verify this observation by conducting an experimental investigation assisted by a simple analytical approach.

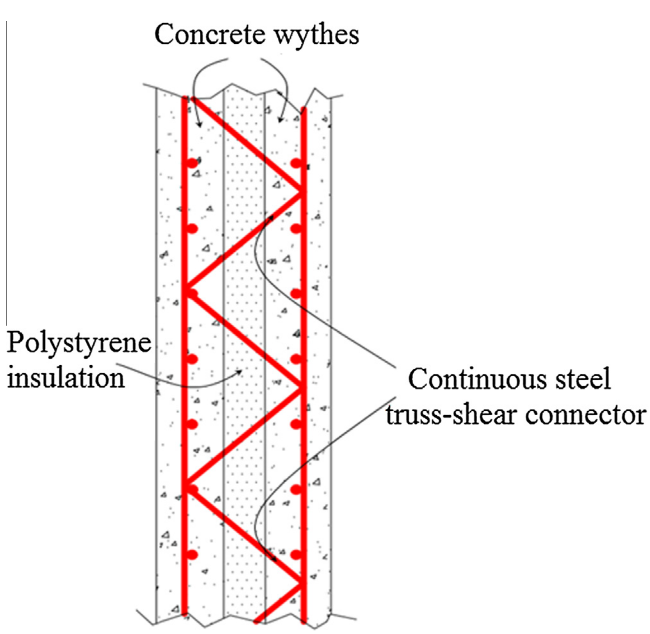

Fig. 1. A continuous steel truss-shaped shear connector.

Meanwhile, information on sandwich panel construction is lacking because of the costly materials necessary to conduct a full-scale experimental testing compared with small-scale testing models [20]. Various proprietary sandwich panel applications are also available in Europe and North America. Hence, their investigators and producers are extremely reluctant to share information with their competitors [12,21]. However, the existing products of PCSP are produced as a heavy system, whose performance suffers in housing constructions, particularly in peat soil. Besides, foundation engineers cannot provide enough bearing foundation to carry the total dead loads of superstores. Hence, calling for a better alternative composite, such as precast foamed concrete sandwich panel (PFCSP), to be developed. Thus, the present research is intensively focused on conducting a full-scale investigation into prefabricating a lightweight system called PFCSP. PFCSPs with different heights were proposed and cast through a foamed concrete (FC) instead of conventional concrete. FC is a light cellular concrete consisting of either cement paste or mortar [22]. It can be classified as a lightweight concrete (density of 400–1900 kg/m^3) with random air voids created from the mixture of foaming agent in mortar. FC is recognized for its high flowability and self-compacting properties, low cement content, low aggregate usage, and excellent thermal insulation [23–26]. It is chosen as an economical solution in formulations of large-scale lightweight applications, such as structural components, partitioning, filling grades, and road embankment infill, because of its easy production process from mobile central plants to final positioning of the components [22,27–29]. FC is commonly used in construction applications around the world [30,31]. It has good mechanical properties; specifically, it contains air content of up to 25% of its total self-weight of which can reduce the dead load of a structure caused by low density on account of the foam agent added [32]. Therefore, it is preferred for. The foam agent usually includes either preformed foaming or mix foaming [33], as shown in Fig. 2. In history, FC was first patented in 1923, and further inclusive study was conducted by Valore [34,35]. Several comprehensive studies on its characteristics and structural behavior have been conducted [22,36–39]. The reduction of structural applications in self-weight helps to decrease the dead loads, foundation size, and labor, transportation, and operating costs [40]. Fire resistance and sound absorbance are also enhanced [41]. Also, lightweight concrete materials are used to reduce the self-weight of the structural elements and to enhance the reduction of earthquake damages because of the influence of structural building global system due to earthquake forces proportionally deal with the structural and building mass. Thus, the utmost reduction of the structure and building mass significantly minimized the degree of risk due to the acceleration of earthquake forces.

Foundation and structural engineers have agreed to develop products to meet future demands for construction materials. These products should be light, durable, easy to construct, and economic in terms of productivity cost and environmental sustainability. Reinforced autoclaved aerated concrete panels for either roof or floor system applications are available [42]. However, an alternative material, namely, FC, can be used with minimal cost control requirements and has the potential to fulfill all structural requirements [43,44]. The adapted traditional use of FC is typically proportioned to achieve compressive strengths ranging from 1 N/mm^2 to 10 N/mm^2. Such compressive strength is only suitable for void fill and trench reinstatement, and is thus disregarded in the production of structural applications [45]. For structural applications, FC strength of at least 24 N/mm^2 at 28 days should be