

PRECAST REINFORCED CONCRETE SANDWICH PANEL AS AN INDUSTRIALISED BUILDING SYSTEM

A. Benayoune¹, Abdul Aziz Abdul Samad², D.N. Trikha³, Abang Abdullah Abang Ali⁴,
A. Monayem Akhand⁵

¹Lecturer, Dept. of MFA, University of Kuala Lumpur-MFI campus

²Professor, Dept. of Civil Engineering, KUiTTHO

³Professor, Dept. of Civil Engineering, UPM

⁴Professor & Director, Housing Research Centre, UPM

⁵Lecturer, Dept. of Civil Engineering, Universiti Tenaga Nasional

Tel: + (603) 8926 2022 Fax: + (603) 8925 8845

Email: benayoune@mfi.edu.my

ABSTRACT Malaysia needs to produce affordable quality homes to house the country's growing population and meets demands arising from migration of people to economic centres in the urban areas. The country is therefore looking for suitable alternatives to conventional building systems to provide affordable quality housing to its citizens. As a part of this effort, the civil engineering department at the *Universiti Putra Malaysia*, has undertaken extensive experimental and theoretical investigations to develop a load bearing system using Precast Concrete Sandwich Panel (PCSP). A description of these investigations is presented in this paper. The paper also concludes with some major results and a discussion of further research is provided.

1. INTRODUCTION

Housing remains a big challenge for many governments, especially in the developing countries of the world. The problem is aggravated by fast increasing population, migration of rural masses into the city and industrial centers and demands for enhanced quality of life. It is difficult to respond to this challenge with traditional building construction systems, as it is essential to meet the housing demand in a short time without sacrificing quality. Due to this inadequacy of traditional building construction systems, new building systems started to appear at the beginning of the 20th century. Today, the Western World seems to have largely overcome the housing shortage, but the problem remains intractable in the developing countries because of financial constraints and lack of appropriate technologies¹.

Industrialised Building Systems (IBS), defined as building systems in which components, prefabricated at site or in a factory and then assembled to form a complete structure with minimum *in-situ* construction, are destined to provide a solution to this multi-dimensional problem, especially since the buildings constructed using this alternative method of construction have a shorter construction time with the additional advantages of strength, integrity, durability, indoor thermal comfort and labour saving. Industrialised construction is carried out in two stages: manufacture of components in a permanent factory or in a workshop or a temporary casting yard near the site of construction and assembly and erection of these precast elements at the construction sites. After assembly of components, they generally require no or only very little finishing. Compared with monolithically cast in-situ concrete structures, precast concrete allows for relatively simple repetitive handling, so that unskilled and semi-unskilled labour can produce high quality products. Furthermore, the concern regarding quality control is transferred from the building site, with all its problems, to the designer's desk and the factory.

For an industrialised building system to be viable, it must have the following three attributes:

- It must satisfy all structural engineering related requirements such as strength, and integrity under imposed loads for the intended storey heights.
- It must be generally economical as compared to conventional systems. This entails, not only cost of materials and labour, but also speed (ease) of construction.

- It must exhibit superior material properties and thermal characteristics compared to conventional systems.

The present paper is limited to cover all issues related to the first attribute. It gives a brief description of research works carried out in Civil engineering department, *Universiti Putra Malaysia*. The Structural behaviour of PCSP when used as building element suitable for low-rise walk-up apartments together with the major findings and recommendations for future research are presented.

2. PRECAST CONCRETE SANDWICH PANEL (PCSP)

Precast concrete wall panel which is currently being used as cladding or curtain walls, does not take any advantage of the panel's structural capabilities. Non-load bearing precast concrete cladding is noted for its diversity of expression as well as its desirable thermal, acoustic and fire resistant properties. However, it is commonly overlooked that precast concrete elements normally used as cladding applications, such as sandwich wall panels, solid panels and spandrel panels, possess considerable inherent structural capacity. The mandatory amount of reinforcement required to handle and erect a precast component is often more than necessary for carrying imposed loads in case of low or medium-rise structures. Thus, with relatively few modifications, many cladding panels can function as load bearing elements. As with all precast concrete applications, further economies can be realized if the panels are repetitive. By making panels as large as possible, numerous economies are realized: the number of panels is reduced and fewer joints (waterproofing requirements), lower erection cost, and fewer connections are required.

Precast Concrete Sandwich Wall Panels (PCSP) function as efficiently as precast solid wall panels but differ in their build-up. Interest in sandwich panels as load-bearing wall panels has been growing over the past few years because manufacturers are looking for more viable products and architects/engineers are pleased with the structural and energy performance, and aesthetics of the sandwich panels. In addition, it has been found that the use of sandwich panels allows the projects to be quicker "dried in" allowing other trades to work in clean and comfortable environment⁶. PCSP acting as load bearing elements are structurally efficient providing economical means of transferring floor and roof loads to the foundations. A PCSP consists of a layer of insulation material sandwiched between two concrete wythes, which are connected by various types of shear connectors (Figure 1).

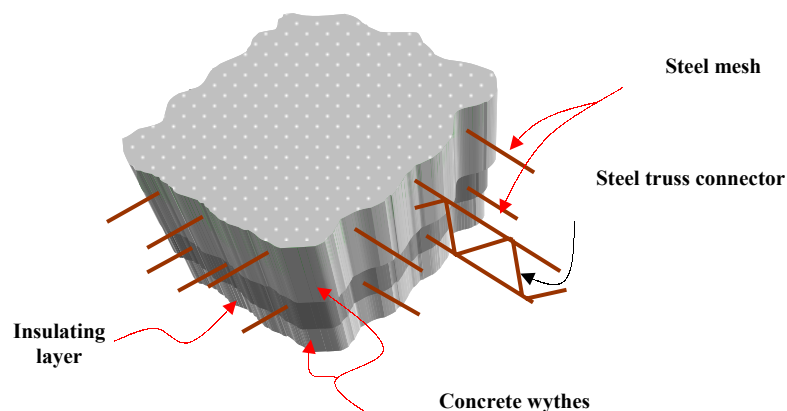


Figure 1. Precast Concrete Sandwich Panel

Depending on the degree of composite action achieved, a PCSP may be regarded as fully composite, semi-composite or non-composite panel. Composite panels are designed and manufactured so that the two concrete wythes act together as a single unit to resist applied loads till failure. This is accomplished by providing full shear transfer between the two wythes. A fully composite panel fails either by concrete crushing or steel reinforcement yielding without failure of the connectors. The fully composite action is reflected in strains remaining essentially linear across the panel thickness, as shown in Figure 2(a). A PCSP is considered to be non-composite if its concrete wythes are tied with connectors that do not have the capacity for longitudinal shear transfer. In this case, the two wythes act independently. The variation of strains across the thickness, in case of non-composite panels is shown in Figure 2(c). In some cases, the panel is designed such that only one wythe, called the structural wythe, resists the applied load as shown in Figure 2(d). A PCSP is considered partially

composite if its connectors can transfer only a fraction of the longitudinal shear as required for the fully composite action. In this case, the connectors fail before concrete crushing or yielding of the reinforcement. Figure 2(b) describes the variation of strain across the panel thickness in such a case.

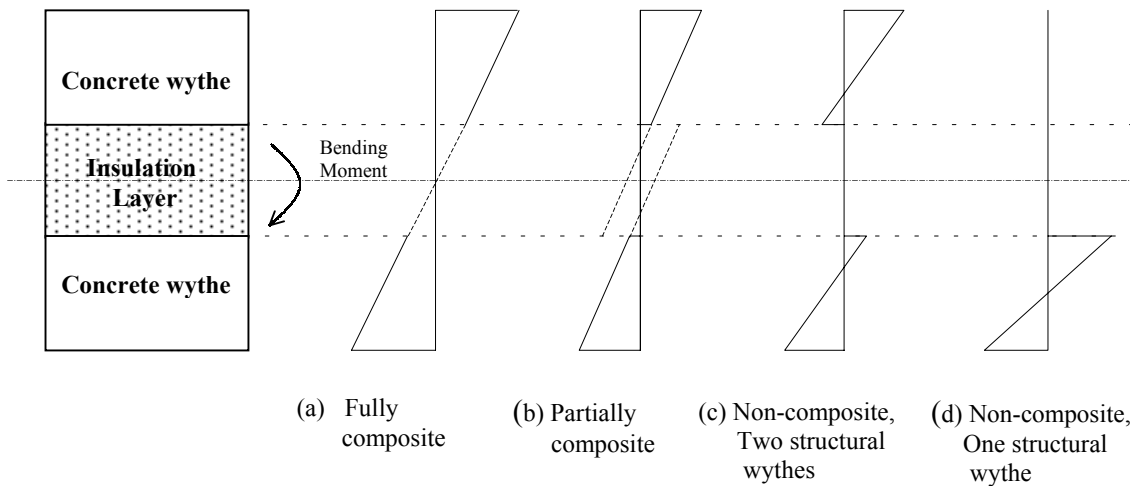


Figure 2. Strain distribution in PCSP under flexure

Extensive experimental and theoretical studies were carried out in the Civil Engineering laboratory, Universiti Putra Malaysia^{1,2,3,4,5}. The aim of these studies is to investigate the structural performance of precast concrete sandwich panels (PCSP) for the development of a load-bearing wall system for use in low-rise buildings. The strength characteristics of PCSP under imposed loads were investigated and the conditions for achieving composite behaviour were observed. In order to reduce the number of different types of elements necessary in the building system, a study on the structural behaviour of PCSP under lateral load was also undertaken so that PCSP can be used as flooring elements, although it is possible to use any conventional flooring system with PCSP as walling units. The vertical connections (connections between wall panels) determine the rigidity and the robustness of the building system. *Cast-in-situ* connections were adopted for investigation.

2.1 PCSP as Wall

The PCSP was examined for its structural performance, as measured by load/deflection behaviour, strain distribution across the thickness of the panel and efficiency of shear connectors and their role in transferring loads from one wythe to the other as well as in ensuring the overall stability of the panel. Behaviour under both axial and eccentric loads was studied. Loads were applied and gradually increased till failure. The influence of wall slenderness ratio on the ultimate strength of the panels was investigated by varying the height of the walls. The shear connector rigidity as defined by the diameter of the connector's bar was also varied to find the optimum bar diameter which ensured stability and high composite action.

Full-scale tests on PCSP under axial and eccentric loads were conducted to obtain test data to validate the proposed FEM model for assessing theoretically the structural behaviour of the sandwich panels under axial and eccentric loads¹. The experimental study consisted of twelve specimens with different heights. The test results were analysed in the context of axial load bearing capacity, load-deformation profiles, load-strain curves, cracking patterns and mode of failure. As the concrete wythes were relatively thin, they were susceptible to buckling especially when the shear connectors did not possess sufficient rigidity for composite action of the panel. The PCSP, therefore, was considered as slender and its analysis had to include the consideration of stability.

The importance of the stiffness of the shear connectors, as measured by the bar diameter was emphasised by establishing minimum needs for the composite action. Equation adopted by ACI equation and expressions proposed by various researchers developed for RC wall strength design were used to analyse the PCSP. Comparisons between results obtained using the classical expressions, FEM results and results obtained experimentally were made to verify whether the classical expressions developed for solid wall were also applicable for PCSP walls.

Opening in the form of doors and windows in the sandwich panels may cause stress concentrations. This effect and the stress distribution in the panels in the presence of openings were studied by using a 2-D FEM model. For this purpose, panels with different types of openings at different locations were subjected to typical service and ultimate design loads as a uniform load at the top edge of the model.

It was concluded that:

- The PCSP can be used safely for low-rise building as their ultimate strength under axial and eccentric loads was at least four times greater than that required to withstand typical 5-storey ultimate design loads.
- The ultimate strength of the PCSP was found comparable to the strength for full composite panels. The panels achieved a high composite behaviour at service and acted in partially composite manner at the ultimate stage.
- The ultimate load was found to decrease with an increase in slenderness ratio (H/t). Under axial load, the ultimate strength decreased by only 11% when the slenderness ratio increased from 10 to 26. Under eccentrically applied load however the decrease was more significant. It was found to be 46% for an increase of slenderness ratio from 10 to 26.
- The strength of the precast reinforced concrete sandwich panels was found to be governed by either material failure through crushing or buckling. The buckling load could be lower than the crushing load if the shear connectors did not have sufficient rigidity leading to premature failure. The buckling strength was affected significantly by the slenderness ratio, the shear connector stiffness and the eccentricity of the load applied.
- The classical analysis using conventional expressions gives satisfactory results so that the proposed empirical expressions can be used safely to assess the ultimate load bearing capacity of the eccentrically loaded panels having $H/t \leq 25$.
- Design guidelines in the form of classical expressions were provided.

2.2 PCSP as Slab

The investigation was extended to explore the feasibility of PCSP as slab^{1,2}. Many issues related to flexural behaviour and design of PCSP such as stress estimation in both concrete wythes, composite action desired and prediction of the forces in shear connectors were addressed.

Two FEM models (2-D and 3-D models) were proposed to simulate the behaviour of PCSP as one-way and two-way acting slab respectively. The FEM proposed models were first validated by experimental data from Ellinna². A parametric study was carried out to study the influence of shear the number of connectors on the ultimate strength and the compositeness of the PCSP working as slab. The investigation included a study of strain distribution, degree of composite action at ultimate and elastic stages of the PCSP, their ultimate strength capacities, load-deflection profiles, and load-stress relationships. A method for the determination of the interface shear force, required for the design of shear truss-shaped connectors was presented. Different aspect ratios of slabs were also chosen to study the effect of the placement and the orientation of shear connectors on the behaviour of PCSP.

- Results obtained by classical elastic theory assuming fully composite action and FEM results were found to be reasonably accurate in predicting ultimate loads and lateral deflections and were comparable to experimental results obtained by Ellinna². In general the computational data were in close agreement with the experimental results.
- At the linear stage, the developed 2-D FEM model can be used to evaluate the amount of composite behaviour provided by the panel under service load. An expression to quantify the degree of composite action was also proposed.

2.3 PCSP Connections

The main objective of this part of the study is to investigate theoretically and experimentally the behaviour of vertical and horizontal L connections typically used in practice for load bearing wall panels construction. Four types of connections were analysed namely, connection A, B, C and D, each connection type differing in shape and length of the anchor steel bar in the connection, which for type A, B, C and D are 105mm, 190mm, 285mm and 289mm respectively. Type D, however has a closed loop extending from the wire mesh in the reinforced concrete wythe. The behaviour of typical vertical connections between two precast concrete sandwich panels under shear and bending using the Finite Element Method was carried out. The non-linear FEM models simulated the experimental specimens carried out by Pang³. A comparison between FEM results and Pang's experimentally obtained results was made. A study on horizontal L connection subjected to combined shear and bending moment was carried out. Ductility of the connection, strain in anchor steel bars, strain in steel, strains variations across the critical zone together with crack pattern and mode of failure were observed.

- The FEM proposed models predicted with a high degree of accuracy the general behaviour of the connections under moment and shear forces.
- All connection types showed brittle manner under pure shear force.
- Connection Type D was found to exhibit superior structural behaviour than other types of connections with regards to the structural strength, the degree of reserve strength and ductility. Hence this connection was recommended.

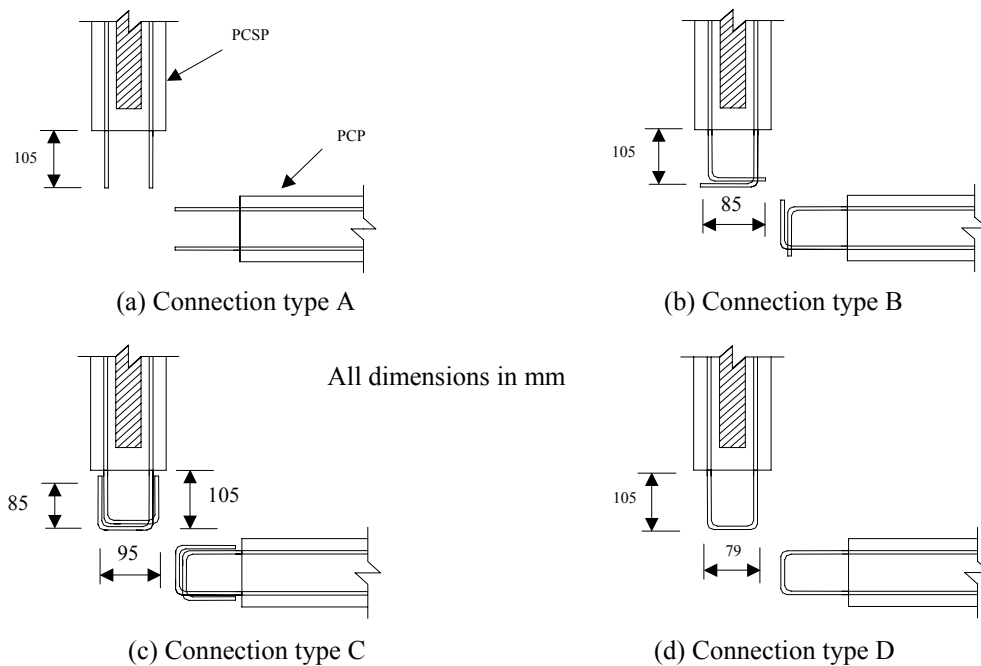


Figure 3. Connection reinforcement details of the cast in-situ connections

3. RECOMMENDATIONS FOR FUTURE RESEARCH

The following issues are in need of further research:

- Full-scale test of PCSP specimens with different size openings at different locations under axial load is needed to demonstrate the efficiency of the recommended steel reinforcement details around the openings.
- Fire rating of the PCSP requires testing of loaded specimen under fire, since the steel shear connectors can lose a large portion of their strength when exposed to fire or high temperature.
- Analysis and testing of the thermal insulation properties of the panels are needed to prove thermal efficiency of the system.
- Experiment test on PCSP connections need to be conducted to study the strength and deformation behaviour of such connections under cyclic loads. This is very significant for the application of PCSP in seismic regions and/or in strong wind areas.

4. CONCLUSION

The paper presented a description and the numerous advantages of Industrialised Building System (IBS) over the traditional building construction systems. It emphasized the need to develop an indigenous IBS in order to meet the shortage of housing demand in a short time without sacrificing quality. The paper also gave a description of the research work carried out in the department of Civil Engineering, *Universiti Putra Malaysia*, to come up with a complete and consistent industrialized building system using PCSP. A presentation of these investigations together with the major findings was discussed. Further research work in need to be addressed was provided. Based on these investigations, it can be concluded that PCSP is a viable and economical industrialised building System.

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