Structural Behavior of Composite Slabs with Different Geometry of Profile Steel Sheets

Ibrahim A. Ali1,2, Amer M. Ibrahim1 and Teeba A. Jassim1

1 Department of Civil Engineering, College of Engineering, University of Diyala, Iraq

2 E-mail: ibrahimabbas790@gmail.com

Abstract. This paper presents the behavior of composite deck slabs with different geometry of profile steel sheet where the strength of composite deck slab mainly depending on the composite action and strength of the connection between concrete and profile steel sheet. In this study, three full-scale specimens of composite slabs with different types of geometry of profile steel sheets (T-shape, triangle shape and trapezoidal shape) were cast and tested under two-point load in order to evaluate the structural behavior and shear bond of composite slabs. The results show that geometry of profile steel sheet have significantly effect on the behavior and strength of composite slab where the ultimate load increased by (32% and 133%) in composite slabs with (triangle shape and T-shape) respectively as compared with trapezoidal shape. As well as the results were satisfy in term of deflection, horizontal end slip, strain and mode of failure.

Keywords: - Composite slabs, profile steel sheet, longitudinal shear, end slip, Failure mode

1. Introduction

Composite deck slabs consist of profile steel sheet and concrete are widely used in the steel-framed structure. The profile steel sheets are used initially as a permanent formwork to carry the weight of wet concrete and subsequently in service stage the profile steel sheet acts compositely with hardened concrete as a tensile member to resist the load applied on the floor. The composite slab decking has many acceptances in the construction industry due to several features including; speed in construction, saving in time, shallower structure, saving in weight and economical construction and other advantages listed by [1-3].

The behavior of profile steel sheet and concrete interface is very complex in the design of composite slab. In general composite slab decking failure can occur in one of three types of failure mode which are: (a) flexure failure, (b) vertical shear failure and (c) longitudinal shear failure. [4]. the most widespread type of failure is longitudinal shear failure due to a weak bond connection between the profile steel sheet and concrete. It is very important to evaluate the shear connection between steel sheet and concrete in the composite deck slab because it affects the strength, structural performance, stiffness and the mode of failure [5], the composite action between profile steel sheet and concrete can be develop by many factors which are: (1) Friction interlock for re-entrant profiles steel, (2) Mechanical interlock provided by deformation of ribs or embossments, (3) Stud connectors or any other local connection between the profile steel sheet
and concrete or End deformation of the ribs at the end of sheeting and (4) using different types of profile steel sheet (trapezoidal, rectangular and re-entrant) [6-7].

In this study, the strength and structural behavior of composite slabs with different geometry of profile steel sheets were investigate experimentally. Three full-scale composite deck slabs were cast and tested under a two-point load in the Laboratory of Structural Engineering and College of Engineering at the University of Diyala to obtain the ultimate load: vertical deflection, horizontal slip, strain of concrete and steel and type of failure.

2. Description of the specimens

The typical cross-section configuration of the composite slabs is shown in Figure 1. In this study, three types of full-scale one-way composite slabs with dimensions (1850 x 500 x 110 mm) were cast and tested. Three different types of geometry from profile steel sheets are used (trapezoidal shape, triangle shape and T-shape) that were approximately equal in cross-section area of steel $A_p = (940 \text{mm}^2$, $973 \text{mm}^2$ and $968 \text{mm}^2$) respectively. The height of the concrete above the flange is 59mm while the depth of the profile steel sheet is 51mm. All three types of profile steel sheets are fabricated locally which act as a permanent formwork in the construction stage to support the weight of concrete and subsequently after concrete hardened act as a tensile reinforcement in the finished floor. Only additional reinforcement steel is provided to control shrinkage and temperature, as well as additional reinforcement in ribs to increase moment capacity.

(a) Composite Slab with Trapezoidal Shape of Steel Sheet.

(b) Composite Slab with Triangle Shape of Steel Sheet.
3. Experimental Work

3.1 Materials

Self-compacted concrete used in this study to cast all three composite slabs with compressive strength (C25/30MPa) design according to (EFNARC,2002) [8]. The profile steel sheets which are used in this work obtained from Ukrainian source with cold rolling and typical dimension 1.25mm thickness, 1.2m width and 2.4 m length. Three types of geometry from profile steel sheets are used in this work (trapezoidal shape, triangle shape and T-shape) that were approximately equal in cross section area of steel $A_P = (940mm^2, 973mm^2$ and $968mm^2$) respectively. All the profile steel sheets are fabricated in Iraq at a local factory as shown in Figure 2. The profile steel sheets are tested according to (ASTM A370) [9] Specification, the yield stress ($f_y=223.4MPa$) and ultimate stress ($f_u=414.98MPa$). Bar reinforcement with a diameter of 4mm used for shrinkage and temperature as well as used in the ribs with two bars in each rib, the yield stress ($F_y=442MPa$) and ultimate stress ($f_u=723MPa$).

(a) Trapezoidal shape of Steel sheet. 
(b) Triangle shape of Steel Sheet. 
(c) T-shape of Steel Sheet.

Figure 2. Geometry of Profile Steel Sheets.
3.2 Preparation of Composite Slabs Specimens

All three profile steel sheets were cleaned thoroughly before casting. The specimens were cast by using a 0.06m³ mixer in the Structures laboratory. No need for a vibrator because SCC is used. Figure 3 shows the composite slabs preparation. All composite slab specimens were water cured after casting, the composite slab specimens have been covered with nylon and after (24 hours) they are stripped off the molds and covered with blanket and sprinkled with water for other (27 days).

![Figure 3. Curing of Composite slabs and Preparation for Casting.](image)

3.3 Test Setup

The composite slab specimens were test after 30 days, before two days of testing the composite slab taken out of curing and left to dry in the laboratory after the specimens dried it clean and painted white to make it easier to observe the crack. The composite slab specimens are simply supported with a clear span of 1650mm and applied to a two-point load. Two LVDTs were used to measure deflections, one in midspan to measure vertical deflection and the other in the side to measure horizontal slip between profile steel and concrete. All the strain gages of steel and concrete were connected to the data logger (TDS-530). Two bearing plates with a thickness of 25mm were place between the load and composite slab to avoid local failure. After that the load applied with an increment of 0.2KN. During the test the measurements were automatically recorded by instruments which included load, vertical deflection, horizontal slip and strain to profile steel sheets and concrete until the failure happened. Figure 4 shows the machine which used to test specimens.
4. Experimental Results

4.1 Ultimate Load Capacity

The ultimate load capacity and other results tested in this study are listed in Table 1. The results show the ultimate load capacity of the triangle shape and T-shape are higher than trapezoidal shape (traditional shape) by (32% - 133%) respectively. The large increase in the ultimate load of the triangle shape and T-shape as compared to trapezoidal shape is due to the interlock between the profile steel sheet and concrete. There is a clear improvement in the bond due to the change in the geometry of the profile steel sheet.

Table 1. The results of tested composite slabs

| Specimens name | P_y (kN) | Δ_y (mm) | P_u (kN) | Δ_u (mm) | Maximum Slip(mm) | Type of Failure | Failure Mode |
|----------------|----------|----------|----------|----------|------------------|----------------|-------------|
| Trapezoidal shape | 30.78 | 11.92 | 45 | 44 | 4.9 | longitudinal shear failure | ductile |
| Triangle shape | ----- | ----- | 59.4 | 7.5 | 7.5 | longitudinal shear failure | brittle |
| T-shape | 90 | 21.42 | 105 | 53.5 | ----- | flexural failure | ductile |

4.2 Load-Deflection Relationships

Load-deflection responses of all the composite deck slabs are shown in the Figure 5. All the composite slabs showed the same trend before horizontal slip happened, after slip happened the curved of composite slab with trapezoidal shape went down and then back up to show ductility behavior (the failure mode of the composite slab is said to be ductile if the load that caused failure exceeds the load which causes the first slip by more than 10% EN 1994-1-1 2004) [10]. A composite slab with a triangle shape showed the same behavior as a trapezoidal shape except it showed brittle failure, while a composite slab with a T-shape acted as a full composite and didn't appear to have any horizontal slip. Generally, the deflection of composite slab with T-shape is less than other two types as compared with the same load and triangle shape less than trapezoidal shape as compared with the same load.
4.3 Concrete Compressive strain

For all the composite deck slabs, the concrete compressive strain was measured at the center on the top of concrete. Figure 6 shows the strain development in the concrete for all the composite slabs. The compressive strain of the composite slab with T-shape developed higher than other types and failed at strain closer to the ultimate strain of concrete at 0.0035. Meanwhile, other types failed at strain less than the ultimate compressive strain because the slip happened before the concrete reached maximum strain.

4.4 Strain of Profile Steel Sheet

Profile steel sheet strain is measured by using strain gage placed in the middle of the profile steel sheet. Figure 7 shows the tensile strain development in the steel sheet. For composite slab with
trapezoidal shape shows developed linearly up to end slip happened but after that a sudden strain increase due to interface bond degradation while the composite slab with triangle shape shows development in strain same trapezoidal shape except it after end slip happened it drop down and failed. Finally, the composite slab with the T-shape showed full composite action and showed an increase in strain until it failed.

Figure 7. Load-profile steel sheet strain.

4.5 Horizontal End Slip Behavior of Composite Slabs

The longitudinal shear failure of the composite slab is said to be ductile if the load that caused failure exceeds the load, which causes the first slip by 10% (EN 1994-1-1; 2004)[10] and according to Eurocode 4 requirements, the composite slab with T-shape and trapezoidal shape behaves ductile while the triangle shape is brittle. The typical end slips between the profile steel sheet and concrete are presented in the Figure 8. The slip in the composite slab with T-shape is zero during all the stage of loading and that indicate the connection between profile steel sheet and concrete is complete interaction while the slip in other types of slabs were zero in early stage of loading but after the slippage starts, the rate of slip got higher and bond showed deterioration and then failed happened. Figure 9 shows the load- slip for composite slabs.

(a) Composite Slab with Trapezoidal shape.  (b) Composite Slab with Triangle shape.
5. Mode of Failure and Crack Patterns

Figure 10 illustrates the composite slab specimens crack patterns and mode of failure under the ultimate load. The specimen with T-shape showed flexural failure and the first flexural crack was at (40kN) without any end slip. While other types of composite slabs showed longitudinal shear failure occurs at the interface of the sheet and concrete. The longitudinal shear failure is initialized by the crack in the concrete under one of the load points, both composite slabs with T-shape and trapezoidal shape showed ductile behavior while composite slab with triangle shape showed brittle failure according to (EN 1994-1-1: 2004)[10].
Figure 10. Mode of Failure and Crack Pattern of Composite Slabs Specimens
6. Conclusion
One-way composite slabs with different types of profile steel sheet were tested under two-point loads, the following conclusions can be drawn:

- The ultimate load capacity of composite slab specimens with profile steel sheets triangle shape and T-shape were higher than trapezoidal shape by (32% - 133%) respectively.
- The composite slab with T-shape shows full connection between steel sheet and concrete and end slip was zero, while the composite slabs with triangle shape and trapezoidal shape show partial connection and the maximum end slip were (7.5mm and 4.9mm) respectively.
- The deflection of composite slab with trapezoidal shape was more than other composite slabs as compared with the same load.
- The composite slab with T-shape failed by flexural failure while the composite slabs with other shape failed by longitudinal shear failure.

References
[1] Johanson, R. (1994). Composite structure of steel sheet and concrete. Volume 1 (beams; slabs; columns and frame for buildings.). Blackwell Scientific Publications, Oseny Mead, Oxford.
[2] Penza, A. (2010). Composite Slabs with Lightweight Concrete. Politecnico Di Milano, Milano.
[3] Rackham, J. W., Couchman, G. H., & Hicks, S. J. (2009). Composite Slabs and Beams using Steel Decking: Best Practice for Design and Construction. The Metal Cladding & Roofing Manufacturers Association in partnership with The Steel Construction Institute, Ascot.
[4] Marimuthu, V., Seetharaman, S., Arul Jayachandran, Chellappan, A., Bandyopadhyay, T. K. and Dutta, D. (2007). Experimental studies on composite deck slabs to determine the shear-bond.
[5] Jeong Y, Kim H, Koo H. Longitudinal shear resistance of steel-concrete composite slabs with perfobond shear connectors. J Constr Steel Res 2009;65(1):81–8.
[6] Burnet Matthew J, Oehlers Deric J. Rib shear connectors in composite profiled slabs. J Constr Steel Res 2001;57:1267–87.
[7] Lakshmikandhan K, Sivakumar P, Sivakumar P, Ravichandran R, Jayachandran S. Investigations on efficiently interface steel concrete composite deck slabs. J Struct 2013;2013:1–10.
[8] EFNARC, F. (2002). Specification and Guidelines for Self-Compacting Concrete. European 29 Federation of National Associations Representing producers and applicators of specialist 30 building products for Concrete (EFNARC).
[9] ASTM A370-17, Standard Test Methods and Definitions for Mechanical Testing of Steel Products.
[10] Eurocode 4. (2004). Design of composite steel and concrete structures - Part 1-1: General rules and rules for buildings. European Committee for Standardization, Brussels.
[11] EN 1994-1-1 Design of composite steel and concrete structures Part 1-1: General rules and rules for buildings. CEN; 2004; p. 1–121.
[12] Ibrahim, A. M., Salman, W. D., & Bahlol, F. M. (2019). Flexural Behavior of Concrete Composite Beams with New Steel Tube Section and Different Shear Connectors. Tikrit Journal of Engineering Sciences, 26(1), 51-61
[13] Fadhil, H., Ibrahim, A., & Mahmood, M. (2018). Effect of Corrugation Angle and Direction on the Performance of Corrugated Steel Plate Shear Walls. Civil Engineering Journal, 4(11), 2667-2679.
[14] Ibrahim, A. M., Said, A. I., & Mubarak, H. M. (2016). Structural behavior of composite reinforced concrete decks with life line steel tube systems. Diyala Journal of Engineering Sciences, 9(3), 104-119.