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Experimental studies on corrugated steel-concrete composite slab

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Scientific paper - Preliminary report

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Experimental studies on corrugated steel-concrete composite slab

Composite deck slabs are composed of normal concrete and corrugated steel sheet. The strength of composite slabs is governed by shear interaction between the concrete and the steel deck. This interaction depends on several factors and no relationship criteria can be found for interaction property from analytical basis. Therefore, the analysis and design methods are used by means of empirical analysis. In this paper, the experimental work is conducted to develop a new scale test method by using two lines of shear connectors welded onto the corrugated plate and lateral beam, in order to increase the shear bond resistance of a composite slab.

Key words:

composite slab, shear connector, corrugated steel plate, longitudinal failure and experimental test

Prethodno priopćenje

Hajir Satih Abbas, Sohaimi Abu Bakar, Mohammad Ahmadi, Zaiton Haron

Eksperimentalno ispitivanje spregnute ploče od valovitog čeličnog lima i betona

Spregnute ploče s čeličnim limovima sastavljene su od običnog betona i valovitog čeličnog lima. Čvrstoća spregnute ploče ovisi o djelovanju posmika između betona i čeličnog lima. Ovo međudjelovanje ovisi o nekoliko čimbenika, a kriteriji odnosa za svojstva međudjelovanja nisu definirani u analitičkom smislu. Stoga se proračunske metode provode pomoću empirijske analize. U ovom radu prikazano je eksperimentalno ispitivanje kako bi se razvila nova metodologija ispitivanja posmične otpornosti spregnute ploče.

Ključne riječi:

spregnuta ploča, moždanik, trapezni čelični lim, otkazivanje posmične veze, eksperimentalno ispitivanje

Vorherige Mitteilung

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Entscheidungsunterstützung zur Verwaltung von Verkehrsprojekten in städtischen Gebieten

Verbundplatten können aus gewellten Stahlblechelementen und herkömmlichem Beton zusammengesetzt sein. Die Festigkeit von Verbundplatten wird durch das Scherverhalten aufgrund der Wechselwirkung von Beton und Stahlblech bestimmt. Diese Interaktion hängt von einigen Faktoren ab und die entsprechenden Kriterien sind derzeit nicht in analytischer Form definiert. Daher beruhen Berechnungs- und Bemessungsverfahren auf empirischen Analysen. In dieser Arbeit sind experimentelle Untersuchungen dargestellt, die zur Entwicklung eines neuen Testverfahrens zur Untersuchung des Scherverhaltens von Verbundplatten beitragen sollen.

Schlüsselwörter:

Verbundplatte, Dübel, Trapezblech, Scherversagen, experimentelle Versuche

1. Introduction

Composite slabs are regarded as one of the best diaphragm strengthening methods. Previous experience indicates that this kind of diaphragm generally allows lower slab thickness (concrete consumption), higher load bearing capacity, and size reduction for structural components (columns, beams, foundations). In addition, this technique is also useful for the use of false ceilings, while also improving planning at various stages of realization. Apart from that, this technology corresponds to two certain requirements: theoretical analysis and mechanical performance technique. According to Figure 1, the cold-formed profiled corrugated steel sheets are used for composite slab decking. They remain in place as a permanent part of the floor system ensuring two functions: they act as a tension reinforcement, and as framework during casting. Moreover, they can provide protection against temperature effects and shrinkage.

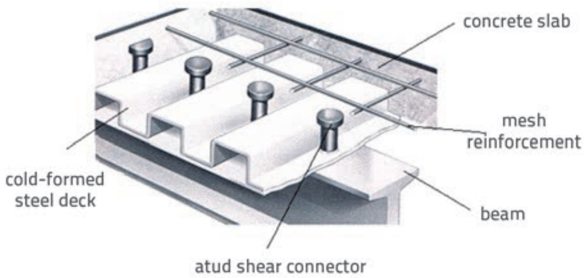

Figure 1. Components of composite construction system

It should be noted that the steel deck has many benefits, the main ones being:
- it increases the quality of construction, it is cost-effective and rapid to install,
- when concrete hardens, a composite action is achieved to resist imposed load,
- it stabilizes the beams against lateral torsional buckling by acting as lateral restraint,
- it transfers in-plane loads by diaphragm action to the vertical bracing system or to the walls,
- it prevents concrete cracking through distribution of shrinkage strains,
- installation of services is simple and openings can easily be made,
- decking is manufactured to high-quality standards at factory, and then is easily transported, handled and cut to length on the construction site, with minimum difficulty and tolerance problems,
- shear connectors are welded to the supporting beam through the decking.

Therefore, based on the above advantages, the composite slab is gaining wide acceptance in structural construction for commercial and industrial buildings. On the other hand, some shortcomings of this system can be highlighted, such as: the susceptibility to fire damage, great attention must be paid to the bonding between the concrete and steel deck, and protection must be provided with regard to deterioration due to high local loads [1]. Even though the steel deck is galvanized, it is recommended to apply anticorrosive paints on the exposed side of the sheet. As shown in Figure 2, the use of embossments on steel sheets makes the composite slab function more efficiently, and this for the following reasons [2]:
- Interaction forces (resistance mechanisms) develop at both ends of the embossments,
- Influence of tilting orientation on slip resistance is reduced and so the strength of adjacent ribs becomes more uniform
- The local bending stiffness of the sheet is increased, and so the total slab slip strength is improved.

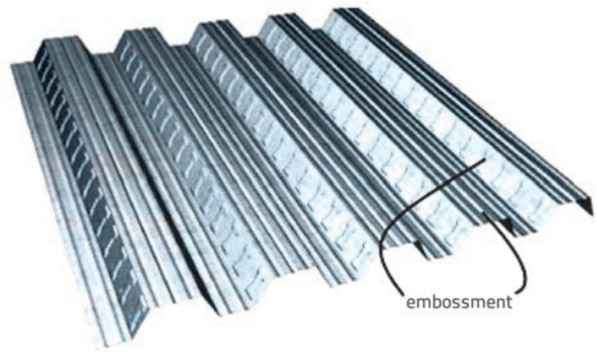

Figure 2. Steel sheet with embossment

The aim of composite construction is to gather different individual material performances to enable the best possible functioning of the diaphragm. The composite steel deck floor is constructed to produce a savings system by bending between the concrete and steel deck using different shear transferring devices. Such devices provide resistance to horizontal slippage and vertical separation between the contact surface of the concrete and the steel sheet. Shear devices with an appropriate form of shear connection, e.g. attaching studs, must be chosen in order to transfer horizontal shear forces at steel-concrete interface of composite slabs. Although there are many forms of shear connections that can be used independently or in combination, the shear-bond capacity must nevertheless be determined through testing. The most common element used is the headed stud (Figure 1) that is normally joined to beam flange through-deck welding. Higher capacity studs (bars, channels, etc.) are also available, but are mainly used in bridges.
Shear connectors (Figure 1) can be classified into full and partial connectors. The full shear connection is achieved when the design bending resistance of the member does not increase due to increase in the resistance of the longitudinal shear connection. If this condition is not satisfied, the connection is partial. The major property required for the design of shear

connectors is the load-slip relationship [3]. The shear bond characteristic of the embossed sheeting is evaluated by two empirical parameters "k" and "m", where "k" stands for friction between them and "m" represents the mechanical interlocking between steel and concrete (Figure 3).

This paper presents experimental testing for the composite deck slab consisting of the concrete and the cold formed profiled sheets with embossments. The compressive strength of concrete is 35 MPa and the use is made of two lines of studs welded on laterals beams through the steel deck. The ultimate load carrying capacity of the composite deck could be calculated to find the slip and deflection due to loads, and the effects of using shear connectors.

2. Failure modes for composite slab

After the concrete slab hardens, it acts compositely with the profiled steel corrugated decks, and carry the imposed live loads. The composite action is completed by adequate transfer of horizontal shear forces between the steel deck and the concrete slab. After that, the deck works as the tensile reinforcement. In addition to horizontal shear forces, the bending action also leads to vertical separation between the concrete and steel. Therefore, the profiled sheet has to be designed to resist vertical separation and transfer horizontal shears. The resistance to vertical separation is provided by appropriate shape of trapezoidal profile, and also by embossments. The following types of failure can be expected when a composite slab is subjected to bending as shown in Figure 3:

a) Flexural failure at section 1-1: this happens when the bending resistance of the slab is exceeded at mid-span (maximum M) and is represented by the moment capacity of the composite slab, based on the full shear connection at section 2-2. This failure mode is dominant in moderate to long slabs with high degree of interaction between the steel and concrete. It is not a controlling design criterion since this type of failure needs a complete interaction at the concrete-steel interface, which is not normally achieved.

b) Vertical shear failure at section 2-2: Dominant in short thick slabs with large loads concentrated near the supports. It occurs when the applied vertical shear force near the support is greater than the vertical shear capacity of the composite slab. This type of failure is rarely critical.

c) Horizontal shear failure (longitudinal slip) at section 3-3: Most frequent failure mode in composite slabs which has attracted most of the research. It occurs when the ultimate longitudinal shear load resistance at the concrete-steel interface is exceeded. It is represented by the shear-bond capacity and is governed by the shear connection at section 3-3. A diagonal crack develops near the concentrated load just before failure, and it is followed by the end-slip between the two materials within Ls. The behaviour of slabs with respect to this failure mode depends on many factors such as the shear transfer devices, steel thickness, and slenderness.

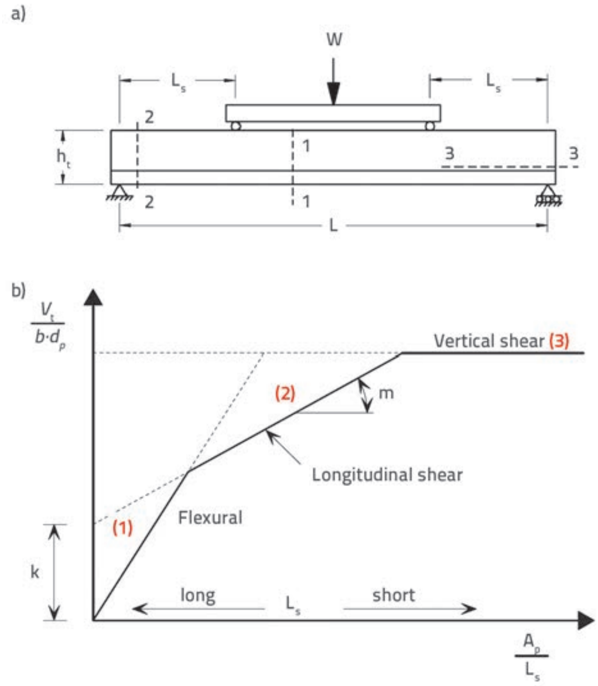

Figure 3. a) Modes of failure for composite slab[3]; b) definition of *m* and *k*

where V_t is the maximum vertical shear, b is the breadth of the specimen, should include a number of complete wavelengths of sheeting, and A_p is the total cross-sectional area of the sheeting. The expected mode of failure is mainly controlled by the slenderness ratio (shear span L_s /effective depth d_p, where the effective depth is the distance from the centroid axis of sheeting to the top surface of concrete). The flexural failure dominates at high L_s / d_p, whereas the vertical shear occurs at low L_s / d_p. The longitudinal shear failure is expected to happen at intermediate values. This behaviour can be classified as either brittle or ductile. In brittle behaviour, the load carrying capacity suddenly decreases due to the relative slip between steel and concrete, which results from the breakage of surface bond. On the other hand, the shear connection in ductile behaviour can transmit shear forces until the flexural or longitudinal shear failure. EC4 classifies the behaviour as ductile if the failure load exceeds the load causing the first recorded slip (greater than 0.1 mm) by more than 10 %. The failure load corresponds to deflection L/50 at mid-span, unless failure has already taken place.

Three stages can be distinguished in the structural action of a composite floor deck system [1]. In the first phase, i.e. during the construction phase (during casting), the corrugated steel sheeting can safely support the fresh concrete. In the second phase (composite slab action), the composite steel concrete deck should support live loads imposed on the slab and, finally, in the phase of composite beam action, the steel beams, which act compositely with concrete during the stud shear connection, must support live loads imposed in transverse direction. This paper deals with the phase of composite slab action, where the behaviour of the composite action of the corrugated steel sheet, and the overlying concrete, and also the shear bond failure of the composite slab, are concentrated.

3. Review of literature

Marimon and Crisinel [4] propose a new design approach for the prediction of composite slab behaviour. This new approach is based on the moment-curvature relationship at the critical cross-section of a composite deck slab by using the combination of results from small-scale tests and standard materials tests with a simple calculation model. This new simplified method is used to predict the bond-carrying capacity of composite slabs through three phases of the M-Θ behaviour observed at critical cross-sections of the composite deck slab.

Oehlers and Burnet [5] present a new type of push-test that simulates bond characteristics by conducting 33 tests. They determine the parameters that influence both the mechanical bond and the chemical bond strength of trapezoidal and dovetailed rib shear connectors. The effects of cross-section geometry, sheet thickness, embossments, and surface treatment, on the bond strength are offered in a form that can be used as guidelines for developing new types of profiled corrugated sheets for slabs, beams and walls.

To study the shear-bond action in composite deck slabs, Chen [6] tested seven simply supported one-span composite deck slabs, and two continuous composite slabs, using various end restraints in the simply supported slabs. The slabs that have end anchorage by using shear connectors were found to afford higher shear-bond strength compared to the case of slabs without shear connectors. The slip between the concrete and steel also reduced.

The purpose of elemental tests [push-tests] conducted in the past was mainly two-fold. First, elemental tests were used as a means for evaluating many parameters that affect performance of composite slabs. These evaluations have refined design procedures or brought about development of more efficient profiles and embossment types (Shen, [22] and Tremblay et al., [23]). The second purpose was to obtain design parameters such as the shear bond property, friction coefficient, ductility characteristic, etc. for use in the design and analysis (Burnet, [10], Patrick, [7], and Veljkovic, [8]).

Leskela and Tenhovuori [9] studied the effects of bond failure in the longitudinal shear connection on the behaviour of composite slabs with the profiled steel sheeting. The effect of different important parameters was considered and critical factors were revised using numerical data obtained from non-linear calculation based on the finite-element method. A comprehensive study was carried out to compare current analytical methods for longitudinal failure as given in the Eurocode 4 [17]. It was established that they can be simplified, improved, and unified, so as to get an obviously comprehensible system describing when the longitudinal failure in a composite slab is possible in the design, and what is to be done in this respect.

Sun and Makelainen [11] studied the shear-connection behaviour of composite deck slabs with a particularly profiled corrugated steel sheeting. Twenty-seven push-out test specimens of different sizes, shapes, locations of embossments, and different steel sheeting thicknesses, were tested in two test series. It was established that the depth of embossments significantly affects behaviour of shear-connections in composite slabs, and reduces the Young's modulus.

Calixto et al. [12] conducted experimental tests on the behaviour and strength of the full scale one-way single span composite deck slabs with ribbed decking. Many parameters were studied, including the shear span length, different steel deck thicknesses, total slab height, and the effect of shear connectors on the end anchorage. The end slips, mid-span deflections, and strains in steel decking, were measured throughout the monotonic loading tests. The test results obviously revealed the best function of the composite slabs with stud bolt connectors.

Wright et al. [13] studied more than 200 tests on composite deck slabs, and compared the results with the available design methods. They studied three distinct phases regarding the structural action of a composite slab system. The experimental tests have shown that the ultimate load capacity has small effect on the divergence in concrete strength. The crucial parameter that has effect on the ultimate strength is the height of the embossment.

Ekberg and Porter [14] conducted a large number of experimental studies on cold formed corrugated steel deck floor slabs. The work involved one way full scale slab elements, which were tested up to failure, and the emphasis was placed on the ultimate strength design concept. Porter et al. [15] conducted experimental studies on the longitudinal failure characteristics of one-way slab elements and reported many findings on considerable parameters influencing behaviour of such elements.

Porter and Ekberg [16] recommended procedures for the design of composite steel deck slabs based on the ultimate strength concepts. The capacity is based on the strength of contact between the concrete and the steel. Porter et al. [15] derived design equations for the shear bond capacity from the data collected from tests on the slabs, and based on establishment of the linear regression relationship. A separate regression is recommended for each deck steel profile, steel surface coating, each gauge thickness of the sheeting, and concrete strength. In the construction phase, the corrugated sheeting is designed for loads due to wet concrete, and it is the self-weight.

Hector and Fernando [21] tested 30 composite slabs with different experimental requirements to assess the influence of the previous cyclic load and the crack inducer placement on the longitudinal shear strength. Tsalkatidis and Avdelas [24] studied the shear connection between the concrete and profiled steel sheeting in a composite slab, with a highly nonlinear problem with regard to boundary conditions. Holomek and Bajer [25] offered a new design approach for the thin-walled cold formed corrugated steel sheet with embossments, used in composite steel concrete slab, with a modern and efficient construction. They also focused

on composite action using the shear connection and its behaviour under different types of loading.
From the literature review, we can conclude that the analysis of the composite slab behaviour is highly complex. Many parameters are needed to investigate the effect of shear bond specifications, such as the shape, height, frequency and orientation of the embossment pattern, and the flexibility and geometry of the profiled sheet itself. Presently, a precise determination of strength can only be made through experimental testing. Experimental tests need to be carried out as every steel deck profile has its own unique shear transferring mechanism. The results of the research offered in this paper are a contribution to new experimental findings on the mechanical behaviour of new composite slabs, and on the analysis of the shear bond behaviour of composite deck slabs by using two lines of shear connectors on every lateral beam support.

4. Experimental studies on corrugated steel - concrete slabs deck floor slabs

4.1 Preparation of composite slab specimen

The composite slab was cast with the profiled corrugated steel sheet as the base. The sheet was completely cleaned before concreting. The composite slab casting was conducted in the fully supported conditions. The slab was 2000 mm in length, 1000 mm in width, and 140 mm in total thickness.
The first step was to produce a composite slab with full connections by welding the bolts with steel corrugated plate and with beam (beam section dimensions are: 254 x 146 x 43), as shown in Figure 4. The steel sheet slab was connected with the top flange of the beam by using stud bolt shear connectors. The bolt was 19 mm in diameter and 100 mm in height before welding, and 95 mm in height after the welding to reduce the horizontal movement of the steel corrugated plate. The number of studs at every line (along the beam) was four (the distance between each was 320 mm, as it should be less than 600 mm), and the distance between the two lines was 80 mm (the standard distance must be at least four times the stud diameter) according to EC-4 [17].

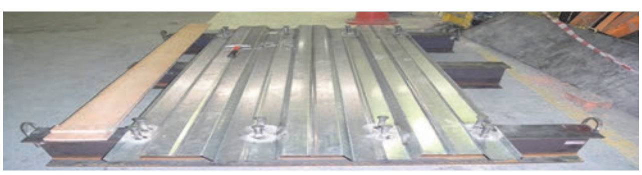

Figure 4. Three compounds bonded together

The mesh steel reinforcement was used to reduce the shrinkage and change in temperature. The bar diameter was 6 mm, and the bar spacing was 200 mm, centre to centre in both directions. These meshes were placed 30 mm from the top surface of the profiled steel sheet, as shown in Figure 5.

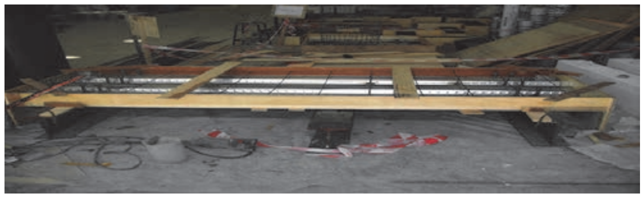

Figure 5. Mesh reinforcement and embossment

The detailing of the steel corrugated deck, and the view of the embossed steel sheet, are shown in Figure 6. All specifications of the experimental model are tabulated in Table 1. The concrete was provided by mixer trucks (ready mix concrete) and the proportion of cement, water and aggregate was 1:0.45:4, respectively. The Portland cement (PC) type II-42.5R was used, and the aggregate was siliceous sand and gravel with the maximum grain size of 20 mm.

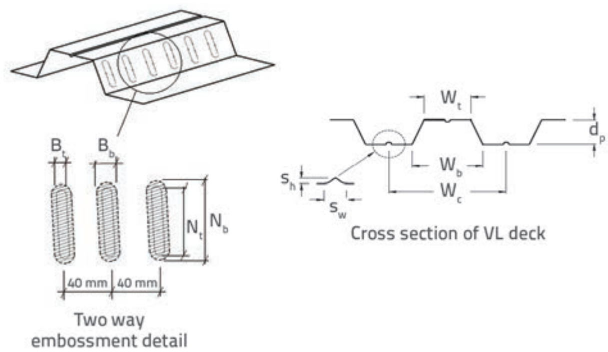

Figure 6. VL deck cross section and embossment details

The compressive strength of concrete was established by conducting compression strength tests after 28 days on six cubes measuring 150 x 150 x 150 mm. The compressive strength amounted to 35 MPa. The slab was cast and cured for 7 days as shown in Figure 7. After 28 days the slab was transferred from the casting area to the testing place using proper supports to avoid flexural deflection.

Where F_y is the normal yield strength and F_u is the ultimate tensile strength of the profiled steel sheeting.

Table 1. Deck section dimensions and properties

Properties / Type	W_t [mm]	W_b [mm]	W_c [mm]	T [mm]	Weight [kN/m²]	B_b [mm]	B_t [mm]	N_t [mm]	d_p [mm]	N_b [mm]	F_y [kN/mm²]	F_u [kN/mm²]	A_s [mm²/m]
2VL20	140	180	320	1	1	10,9	9,1	29	58	36	460	500	1056

Figure 7. Concrete casting and curing

4.2. Experimental set up

Figure 8 and Figure 9 show the actual view for the experimental setup of the composite deck slab. The beams were supported by the strong steel plate at the beginning and at the end of the beam.

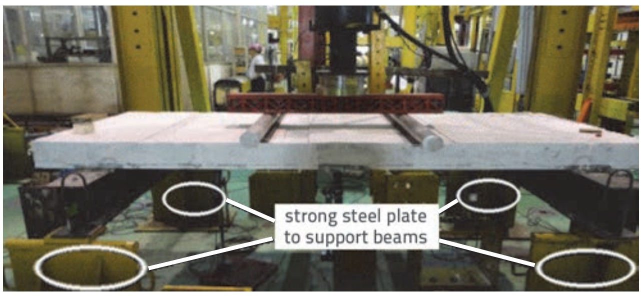

Figure 8. Set up of composite slab

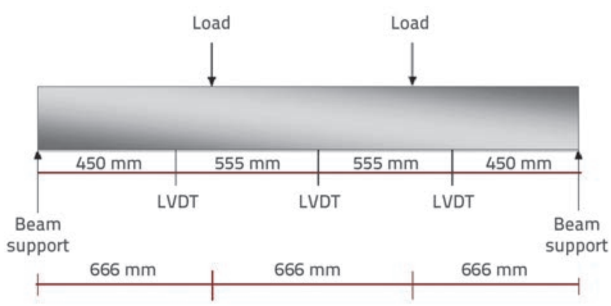

Figure 9. Composite slab dimensions and distances

Figure 10. LVDTs at centre and quarters of the slab.

The main goal of the tests was to measure the maximum load capacity of composite slab under the limit deflection. Therefore three LVDTs were put under the slab: one at the mid span and the other two at the distance of L/4 from the right-hand and left-hand sides, as shown in Figures 9 and 10.

The end slip between the concrete and steel is important to determine the ductile or non-ductile behaviour of the connections. For this purpose, two LVDTs were used at every side of the composite slab; one on the concrete and the other one on the corrugated steel sheet, as shown in Figure 11. All LVDTs were connected to a computer which automatically stored all the data for the given time interval. Thus recorded results are shown in some of the figures below. The computer recorded the load history for each given time interval (the rate was 0.03 kN/s). Two line loads were applied to the composite deck slab across the width of the slab by using two smaller cylinder sections (20 mm in diameter, 1500 mm in length, and 2 kN in weight). A transferring device was used between the point load and the slanders for load distribution (beam section; W 245 x 102 x 22). The cylinders were placed on the steel plate (10 mm in thickness, 1000 mm in length, and 0.5 kN in weight), as shown in Figure 12.

Figure 11. LVDT transducers used to measure end slip between steel and concrete

Figure 12. Transfer of two lines load onto the slab.

4.3. Static test

The specimen was placed on strong steel supports and the line loading and shear span were marked, where the shear span is the distance between the centre of supports and the line load application point. The rate of load adopted for static test was 0.03 kN/s, and the failure occurred after 70 minutes. The server computer automatically recorded the mid span deflection, the deflection under the quarter of the slab, and the slip in the concrete at the end of the composite slab at every 5s. Simultaneously, the maximum mid span deflection was limited to 40 mm in order to avoid sudden collapse of the specimen (EN 1994-1-1 [17]).

5. Results and discussion

5.1. Load deflection behaviour

The load-deflection curve of a typical specimen is shown in Figure 13. The specimen eventually collapsed due to horizontal separation of the steel deck from concrete, as shown in Figures 14 and 15. Porter and Ekberg [20] indicate that the failure of a steel-deck-reinforced concrete slab initiates by irregular development of the flexural and bond stresses between the concrete and steel deck and continues until the bond strength is exceeded and local bond failure occurrs. When the loss of bond progressively reached to the free ends of the slabs, the slippage between the concrete and steel occurred, with eventual collapse. The composite action was not completely lost because of the shear studs that acted as anchors, transferring the forces from concrete to the steel deck. The maximum load and maximum deflection were 120 kN and 40 mm, respectively (these amounts are still within the EC-4 limits).

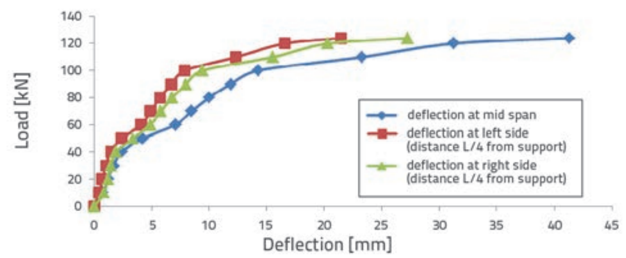

Figure 13. Typical load - deflection

Figure 14. Typical specimen after failure

Figure 15. Vertical separations in side of slab

5.2. Load-end slip behaviour of slabs

The composite slab test resulted in shear bond failure with significant slips recorded at the ends, while major cracks occurred at the critical section under one of the two line loads. The initiation of shear-bond slip at the sheet-concrete interface reveals a loss of interaction in composite action. In simply supported composite slabs, the shear-bond slip develops with load increment, leading to flexural cracks in concrete and final failure of the composite slabs. The slip (horizontal movement) is measured between the concrete and corrugated trapezoidal steel plate by placing two LVDTs at each side of the composite slab. After the loading, the result of the two LVDTs, and the difference between the horizontal movement for concrete and steel (slip), were recorded. Then the average slip for two points was taken as shown in Figure 16. It can be noticed that the slip until the load 40 kN was equal to 0.04 mm. After 40 kN, the end slip increased and the behaviour of the load-deflection curve changed from the elastic linear to plastic nonlinear and also, at same time, the first cracks appeared under the line load, with the crack width of 0.1 mm only. The load carrying capacity of composite slab was governed by the longitudinal shear-bond failure.

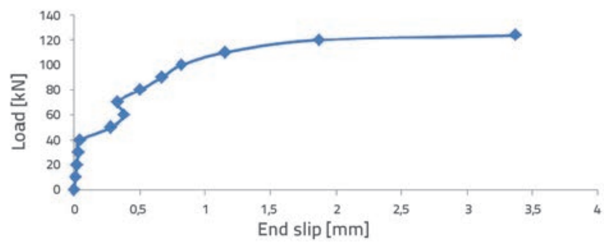

Figure 16. Typical load – end slip

The slab test revealed a ductile behaviour. This behaviour was observed at the load-deflection curve when the maximum load (W_t) at the composite slab failure was 120 kN, and the first load cause slip ($W_{1\ slip}$) was 15kN and the load cause slip 0.1mm ($W_{0.1\ mm}$) was 45 kN. In addition, as shown in EC-4, the ductile behaviour of the slab occurs when the value of W_t is at least 10 % higher than $W_{0.1\ mm}$ (the ratio $W_t/W_{0.1\ mm}$ = 2.667 was greater than 1.1)

5.3. Efficiency of composite slab with two line stud connectors.

Composite slabs with end anchorage of steel shear connectors were found to afford higher shear-bond strength compared to composite slabs without end anchorage. The most effective and the most commonly used shear connection device is generated by the pressed embossment on the profiled steel surface [26-27]. The shear-bond strength was checked based on linear regression of test results for one-span composite slabs with end anchorage. By using end anchors of shear studs, the load-deflection curves were almost linear (before the shear-bond slip initiation, which was detected at the slab ends). After the load increase, the shear-bond slippage increased, with the de-bonding cracking at the sheet-concrete interface. The load-deflection curves then became non-linear.

In slabs with no end anchors, the shear-bond slip occurred close to maximum load. The effect of the end anchorage on the shear-bond resistance can be considered as a restrained tensile strut in the steel corrugated sheeting. It is formed during flexural bending in the slab, which will influence its shear-bond resistance. The end anchorage is usually more flexible than the longitudinal shear-bond interface (which is relatively brittle). Therefore the effects of the shear-bond and the end anchorage can not directly be combined [20].

In this study two lines of shear connection were used to increase the shear bond resistance and, consequently, the load capacity and composite slab ductility increased, as clearly shown in Figure 17. The result of this test (two line studs) was compared with the results obtained by Omg [18] and Redzuan [19] who use the same properties of material and composite slab dimensions, as shown in Figure 17. However Omg [18] and Redzuan [19] tested composite slab without using shear connection. In addition, the slip result obtained in this study, and results obtained by Redzuan [19] were compared, as shown in Figure 18.

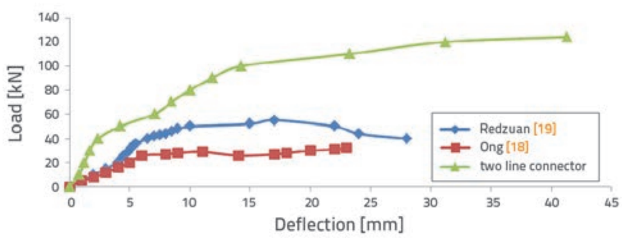

Figure 17. Load vs deflection at mid span

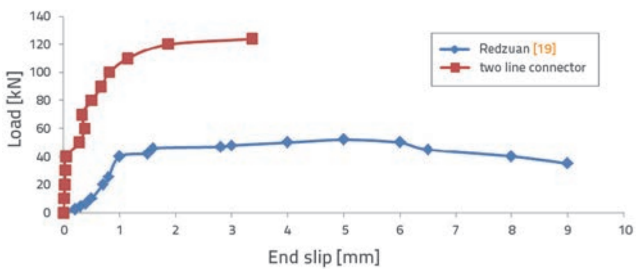

Figure 18. Load vs end slip

By utilizing two lines of studs (stud capacity amounts to 91 kN), the interaction between the corrugated steel plate and concrete improved and, therefore, the shear bond resistance was high and the slip between them was low. The slab with end shear studs would give adequate warning through excessive deflection prior to failure, as shown in Figure 19 (many cracks appear before the failure).

Figure 19. Composite slab cracking before failure

6. Conclusion

A new type of the scale composite slab test was successfully developed. The scale test developed in this research can be used for performance evaluation, and can also provide data for use in current design methods (m-k method, and PSC method). This study was conducted to determine the shear bond capacity of concrete slab with steel deck after adding two lines of shear connectors, welded on the lateral beam with the steel sheet. The expected result was achieved: maximum capacity and slippage capacity amounted to 120 kN and 3.5 mm, respectively. Experimental results show that the composite slab has high ductility, and that the end slip is very small compared to the composite slab without shear connection. The behaviour of the load-deflection curve before slippage was linear and, when the slippage increased, the behaviour changed to non-linear, and the composite slab behaviour simultaneously changed from elastic to plastic. The concrete cracking was small because the mesh reinforcement was used to prevent the creep and shrinkage of concrete.

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