Non-linear behavior of composite two way slab with screws as shear connectors under equivalent uniform distributed repeated load

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Abstract: The research studies experimentally behavior of composite two-way slab that consist of flat steel plate and concrete with screws as shear connectors. The screws differ in length and diameter with distributed of them according to shear stresses [dense distribution nearest from support] and by using the same weight of screws in each slab (819±8) g.

Six composite slabs was cast in this work and tested under equivalent uniform distributed repeated load [EUDRL]. The various parameters were investigated in this work including the diameter of screws (6.3, 4.2, 3.5) mm and length of screw (25 and 12.5) mm.

The results of the present experimental study demonstrated that the composite slab with diameter of screws (4.2mm) and length (12.5mm) is the best among others composite slab in this work. The strength of the best tested composite slab (using screws of (4.2mm diameter and 12.5mm length) is closed to that of reinforced concrete slab (R/C) with difference about (7.1%). On other hand, the ductility of composite slab is better than of (R/C) slab by about (6.7% to 24.74%).

1. Introduction

The requirement for the cost and time of construction without needed to mold resulting in an increase in the use of composite structure. To increase the strength and stiffness of composite structure, the slip between concrete and steel plate must be decreased by using shear connector such as screws, stud, embossments, epoxy and other type of shear connector. The strength of shear connection depends on two important factors, namely shear strength of the shear connector and resistance of composite slab to longitudinal cracking.

The behavior of shear connector between steel beams and composite slab was studied by kim et al.[1] and the effect of support condition, different loading, width of concrete slab and inclusion of profiled steel sheeting have been discussed. Self-drilling bolts (6.35mm * 19.05mm) (diameter*length) was used as shear connector in composite slab by Andrade [2] by installing it on the top flange of steel sheeting and it is increase the ultimate load and the stiffness of the specimen.

Ellobody and Young [3] studied the effect of different profiled steel sheeting geometry, head shear stud diameters and heights as well as concrete strength by using the finite element models. Mirza and
Uy [4] using three dimensional non-linear finite element to studied the effect of the combination of axial and shear loading on behavior of head stud. The results indicate that the strength and the load-slip behavior influenced by the combination of loading condition.

Qureshi et al. [5] investigate the influence of position of shear stud and profiled sheeting thickness on the strength, failure modes and ductility of the headed shear stud by using three-dimensional finite element model. Qureshi and Lam [6] studied the behavior of head shear stud in composite beam using static and dynamic finite element model.

Pereira et al. [7] studied the vertical shear design model for composite slab where the slabs were tested to force vertical shear failure, instead of a longitudinal shear failure. Bonilla et al. [8] investigate the effect of concrete strength on shear resistance of stud connector and from the results found that the resistance of the shear connection is increased with the increase of concrete strength.

2. Experimental program

2.1 Description of samples

The same geometrical dimensions six composite slab (concrete- flat plate) (900*900*60) mm (length *width* thickness) where thickness of concrete (59.2 mm) and thickness of plate (0.8mm) as shown in 'figure2' and 'figure3' and using the screws as shear connectors that shown in 'figure1'.

![Figure1](image1.png)

**Figure1.** The screws that used as shear connector.

Distributed of these screws according to the shear stresses, the length and diameter of screws change from one slab to another where the slabs was divided in two groups depending on length of screws, three slab with length of screws 25mm and three with length of screws 12.5mm, in each group there was three diameter of screws (6.3, 4.2, 3.5) mm, in addition one R/C slab with reinforcement (diameter 10 mm) (without steel plate) is cast and tested. All slabs under equivalent uniform distributed repeated load (EUDRL), the details of all slabs as shown in 'figure 2’. The distribution of screws in slabs specimen as shown in Table 1.
Table 1. The distribution of screws in slabs specimen and the divided of each group.

| Classification of specimens | Slab designation | No. of screws | Spacing between screws (mm) |
|-----------------------------|------------------|---------------|----------------------------|
| Group A                     | CSNDS (25*6.3)   | 148           | 47-55                      |
|                             | CSNDS (25*4.2)   | 340           | 50-64                      |
|                             | CSNDS (25*3.5)   | 696           | 32-52                      |
| Group B                     | CSNDS (12.5*6.3) | 284           | 50-64                      |
|                             | CSNDS (12.5*4.3) | 576           | 32-52                      |
|                             | CSNDS (12.5*3.5) | 828           | 24-46                      |
| Reference Model             |                  |               |                            |
|                             | Reinforced concrete slab with diameter of reinforcement steel (10mm) in two direction |

Where:

CSNDS: Composite Slab with Non-uniform Distributed Screws (size of screws) (diameter*length)
Composite slab with size of screws (4.2* 25) mm (diameter*length) (CSNDS (4.2*12.5))

Composite slab with size of screws (3.5* 25) mm (diameter*length) (CSNDS (3.5*25))

Composite slab with size of screws (6.3 * 12.5) mm (diameter*length) (CSNDS (6.3*12.5))

Composite slab with size of screws (4.2*12.5) mm (diameter*length) (CSNDS (4.2*12.5))
2.2 Material properties

The average compressive strength was 68MPa at 28 days. For deformed bar of diameter (10mm) the measured yield strength and the ultimate strength were 422MPa and 582MPa, respectively. The dimensions of flat plate steel sheeting (dog-bone) model for tensile test according to (E8/E8M-13a).

Figure 2. cross section for all slabs in this work.
the result of tension test for two coupons of steel sheet were 365MPa for yield stress and 362.07 MPa for ultimate stress.

2.3 prepared the models

After drilling all plate to installations the screws the material, molds and reinforcement was prepared then casting and curing all slabs as shown in 'figure 3'.

![Drilling the plate](image)

![Prepared the materials](image)

![Casting of specimens](image)

![Prepared the molds](image)

**Figure 3.** Stag of prepared the specimens.

2.4 loading frame, supports and position of dial gages

The equivalent uniform distributed repeated load was applied at the top surface of the concrete and using rubber plate to avoid non-uniform stress distribution as shown in 'figure 4'. Simply supported was used in two side and roller from two other side. Three dial gages were used, two in neighboring side to measure and knowing the sliding of concrete and one dial gage in the center of slab from bottom to measure the deflection.
2.5 loading procedure

The repeated load was applied cyclic until up to failure. Each cycle consists of two steps, first step was loaded up to selected level from ultimate load of control and the second step was unloaded to zero. The level of loading that been selected were (0.23Pu, 0.46Pu, 0.69Pu, ..up to failure of specimen). Where, Pu is expected ultimate load of composite slab with screw’s size (6.3mm diameter and 25 mm length). Each level of load is consisted of four cycles as shown in 'figure 5'. The first cracking load and its location were recorded. At each load increment, observations of crack development on the concrete slab was traced by pencil. The loading was continued until failure load. The failure of the slab specimens was declared when no further increase in the loading readings was recorded.

2.6 Results of experimental work of slab specimens.

The results of testing for all specimens as shown in Table 2.
Table 2. Results for specimens tested under equivalent uniform distributed repeated load (EUDRL)

| Slab designation | $P_u$ (kN) | $P_{cr}$ (kN) | $P_{cr}/P_u$ (%) | $\Delta V_{max}$ (mm) | $\Delta s(65\% P_u)$ (mm) | Max. side slip (mm) | Type of failure |
|------------------|------------|---------------|------------------|------------------------|---------------------------|-------------------|-----------------|
| CSNDS$_{(6.3*25)}$ | 180        | 70            | 38.88            | 29.6                   | 9.46                      | 0.97              | flexural failure |
| CSNDS$_{(4.2*25)}$ | 240        | 158           | 65.83            | 25.77                  | 7.27                      | 1.78              | flexural failure |
| CSNDS$_{(3.5*25)}$ | 240        | 150           | 62.5             | 25.5                   | 7.38                      | 2.29              | flexural failure |
| CSNDS$_{(6.3*12.5)}$ | 200        | 73            | 36.5             | 28.4                   | 10.92                     | 1.4               | flexural failure |
| CSNDS$_{(4.2*12.5)}$ | 260        | 168           | 64.6             | 27.4                   | 8.11                      | 2.37              | flexural failure |
| CSNDS$_{(3.5*12.5)}$ | 258        | 162           | 62.8             | 27.6                   | 8.36                      | 2.38              | flexural failure |
| RC slab          | 290        | 65            | 22.4             | 29                     | 11                        | 1                 | flexural failure |

The failure that was happened in all composite slabs under equivalent uniform distributed load is flexural failure and there was few separation between concrete and flat plate and this separation appear clearly in slab that used large diameter of screws. The failure of slabs was on the top of slabs as shown in 'figure 6.'

At the end of test the plate was tear especially at the edge of the slab.

![Figure 6](image_url)
The failure that happened in reinforced slab also flexural failure.

After test all slabs under equivalent uniform distributed repeated load it was found that the slab with diameter of screws 4.2 mm and length (12.5 mm) is the best to earn extra time during construction with lower cost and without needed to mold from the bottom of the slab because found the plate. The difference for other slab as shown in Table 3.

### Table 3. The difference between composite slab and R/C in failure load.

| Slab designation | $P_f$ (kN) | the difference(%) with RC slap $\left(\frac{P_f(RC)-P_f(composite)}{P_f(RC)}\right) \times 100$ |
|------------------|-----------|-------------------------------------------------|
| CSNDS (6.3*25)   | 180       | 35.7                                            |
| CSNDS (4.2*25)   | 240       | 14.28                                           |
| CSNDS (3.5*25)   | 240       | 14.28                                           |
| CSNDS (6.3*12.5) | 200       | 28.6                                            |
| CSNDS (4.2*12.5) | 260       | 7.1                                             |
| CSNDS (3.5*12.5) | 258       | 7.86                                            |
| RC slab          | 280       | 0                                               |

3. Discussion of the results

#### 3.1 Effect of screw's diameter and spacing for the same weight of screws in each slab (819±8)g

In the first group (group A) the slab with diameter (6.3 mm) and distributed according to the amount of shear stress failed at load (180 kN) while the second slab with diameter (4.2 mm) failed at load (240 kN) which is greater than the first slab at percentage 33% (1.3 times) while the third slab failed at load (240 kN) it is greater than first slab at percentage (33%) and the same as in the second slab but with lesser number of load cycles where the second slab failed in (240 kN 3rd cycle of load step 240 kN) while the third slab failed in (240 kN 2nd cycle of load step 240 kN). In another words, the best screw is (4.2 mm) also.

Also, in the fourth group the slab with diameter (6.3 mm) and distributed according to the amount of shear failed at load (200 kN), where the second slab with diameter (4.2 mm) failed at load (260 kN) which is at percentage 30% greater than first slab, where the third slab failed at load (253 kN) it is greater than first slab at percentage (26.5%) and less than the third slab. Figure 7 show the effect of diameter for screws with spacing on load of failure.

From the test results it is clear that (for the same weight of screws), in case of reducing the diameter subsequently reducing the spacing between screws gives a better distribution of stresses between the screws and the concrete surrounding them, but up to a point perhaps these stresses will overlapped between the adjacent screws and gives a higher concentrate stresses. Therefore; it results in lower
capacity. Hence, the composite slab with diameter of screws (4.2 mm) and length (12.5 mm) is the best among other slabs and approaching to the RC with difference of 7.1\% only.

![Graph showing load vs. diameter of screws]  
**Figure 7.** Effect of Diameter for Screws after using the same weight of screws in each slab

### 3.2 Effect of length of screw

After using the same weight of screws in each slab was found, the first slab with size of screw (6.3, 25) mm (diameter, length) in the first group was failed at load (180 kN, C^4\text{th}, load step 180 kN) while the first slab from second group size of screws (6.3, 12.5) mm was failed at load (200 kN, C^3\text{rd}, load step 200).

The second slab in the first group with size of screws (4.2, 25) mm was failed at load (240 kN, C^3\text{rd}, load step 240 kN) while the second slab from second group failed at load (260 kN, C^1\text{st}, load step 260 kN), and the third slab from first group size (3.5, 25) was failed at load (240 kN, C^2\text{nd}, load step 240 kN) while the third slab from second group (3.5, 12.5) mm was failed at load (253 kN, C^1\text{st}, load step 260 kN).

These results emphasized the fact is the screws of shorter length is better. However, such fact needs more verification and may be there is an optimum screw’s length and diameter, for the same weight of screws.

### 3.3 Tearing of the plate

Tearing the plate is happen when moving of screws towards the edge specially the screws that near from the edge as a result the horizontal shear that comes the vertical applied load.

from test observed the creep in the first slab from first group (group A) CSUDS_{6.3,25} is greater than the creep for first slab second group (group B) CSUDS_{6.3,12.5} (6.3, 12.5) mm as shown in **figure 8**.
second slab from first group (group A) CSUDS$_{4.2,25}$ have creep greater than second slab from second group CSUDS$_{6.3,12.5}$ and so on.

**Figure 8.** Tearing in the plate
3.4 Load-deflection curves

During the test for all the slabs one dial-gauges was installed in the mid span to record the deflection of the slabs to find the behavior of the load-deflection curves. Load-deflection curves for all slabs as shown in 'figure 9'.

![Load-deflection curves for composite slab](image-url)
4. Ductility

The ductility for a structural member could be defined as the capability of the member to experience significant deflection before failure. This property is essential for structural members subjected to seismic loads as well as cyclic load since it provides signs of failure beyond yielding and before failure. The proportion of ductility for all slabs is calculated as shown in Table 4.

It is clear that, in general, the ductility of the composite slabs is much better than that for conventional R/C especially those of optimal screw diameter (4.2 mm) and length (12.5).

Table 4. Ductility for Concrete Slabs Evaluated under equivalent uniform distributed repeated load

| Model ID     | $P_u$ (kN) | $\Delta_u$ (mm) | $\Delta_y$ (mm) | $\mu = \frac{\Delta_u}{\Delta_y}$ |
|--------------|------------|-----------------|-----------------|----------------------------------|
| CSNDS6.3,25  | 180        | 29.6            | 9.4             | 3.15                             |
| CSNDS4.2,25  | 240        | 25.77           | 7.65            | 3.37                             |
| CSNDS3.5,25  | 240        | 25.5            | 7.62            | 3.35                             |
| CSNDS6.3,12.5| 200        | 28.4            | 8.35            | 3.40                             |
| CSNDS4.2,12.5| 260        | 27.4            | 7.95            | 3.45                             |
| CSNDS 3.5,12.5| 258       | 27.6            | 7.5             | 3.68                             |
| R/C slab     | 280        | 29.4            | 9.96            | 2.95                             |

5. Conclusion

1. There is an optimum length of screws for the best capacity for (EUDRL) and in this studying the best is screw of length (12.5 mm).

2. The capacity of the best dimension of screws approaches the capacity of reference RC slab with differ not more than 11.5%. However, it is more economical and easier in construction.

3. The ductility of composite slab with screws is much better than the ductility of reference RC slab by about (6.7%-24.7%) so, it is more effective in the case of repeated load (like bridges).

4. The deflection in composite slab at service load is lower than that of R/C slab by (0.727%-33.9%)
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