Ultimate Load Capacity of Composite Concrete-Steel Deck One Way Slab

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Abstract

Ultimate capacity of composite concrete-steel deck (a composite slab) is the topic of this study. A composite slab consists of two or more structural components of different materials. The main aim of using a composite slab is to make full use of the beneficial properties of different materials. The upper and lower components in a composite slab are usually connected together by shear connectors.

The present study is concerned with the ultimate capacity of composite concrete-steel deck-one way slabs (composite slabs), the ultimate capacity of composite slabs with longitudinal bars and ultimate capacity of composite slabs with shear reinforcement. The study also includes the effect of using different spans of steel decks.

The tested slabs are loaded to failure by means of two-point load tests. It is found that a composite slab with longitudinal bars (RLB) gives high Ultimate load capacity. The mean ratios of ultimate load capacity for the composite slabs with longitudinal bars (RLB) to reference slabs (RS) are (1.78) and (1.98) of slabs which have length equal to (1600mm) and (1300mm), respectively. The mean ratios of ultimate load capacity for the composite slabs with shear reinforcement (RSR) to reference slabs (RS) are (0.99) and (0.92) for the slabs which have lengths equal to (1600mm) and (1300mm), respectively. Then, the ultimate load capacity of slabs (RSR) is less than the ultimate load capacity of slabs (RS). It can be concluded that use of shear reinforcement does not increase the ultimate load capacity. The mean ratios of ultimate load capacity of slabs with lengths equal to (1300mm) to (1600mm) are (1.07), (1.19) and (0.986) for slabs (RS), (RLB) and (RSR), respectively.

الخلاصة

تحمل السقوف المركبة من الخرسانة والأشكال الفولاذية التي تنقل الأحمال باتجاه واحد هو محور هذا البحث والذي يتضمن دراسة مختبرية لتحمل السقوف المركبة بسيطة الإسناد المكونة من العتبات الخرسانية والأشكال الفولاذية المرتبطة معاً بالروابط القصية ودراسة تحمل لسقوف المركبة مع إضافة حديد تسليح في منطقة الشد(RLB) ودراسة استخدام حديد مقاوم للقص(RSR) ودراسة تأثير تغيير طول الفضاء للسقوف المركبة.

ويمكن إن نستنتج أن استخدام حديد تسليح طولي يسهم بشكل كبير بزيادة مقاومة السقف للأحمال المسلطة حيث تصل نسبة تحمل السقوف المركبة مع إضافة حديد تسليح في منطقة الشد (RLB) إلى السقوف المركبة(RS) حوالي (1.78) و (1.98) للسقوف التي بطول (1600 mm) و (1300 mm) على التوالي. كما أنه تصل نسبة تحمل السقوف المركبة مع إضافة حديد مقاوم للقص(RSR) إلى السقوف المركبة(RS) حوالي (0.99) و (0.92) للسقوف التي بطول (1600 mm) و (1300 mm) على التوالي ونستطيع إن نستنتج أن استخدام حديد مقاوم للقص للسقوف المركبة لا تزيد التحمل الأقصى.

وكان معدل نسبة التحمل الأقصى للسقوف المركبة طول (1300 mm) إلى (1600 mm) هي (1.07) و (1.19) و (0.986) للسقوف المركبة (RLB) و(RS) , (RSR) على التوالي.

1. Introduction

The structural member of two or more materials is known as a composite member. Composite slabs, as a part of composite steel framed buildings and comprise concrete slabs spanning between supports and profiled steel decking (or sheeting), as shown in **Fig.(1)**.

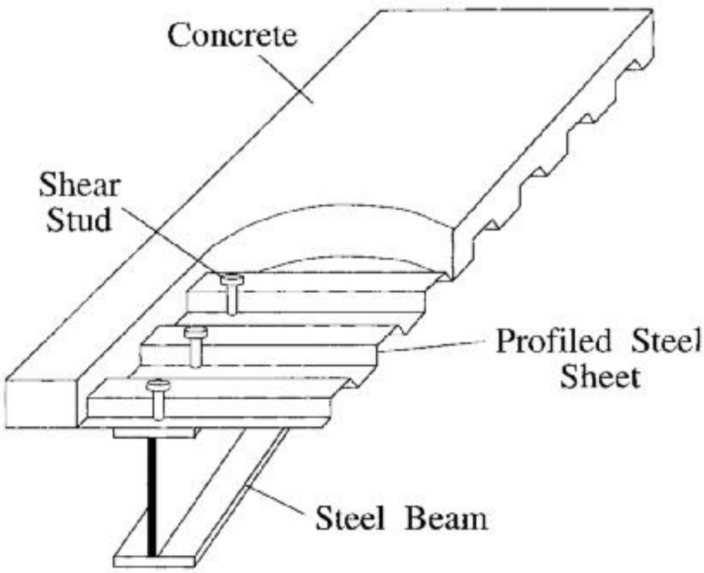


Figure (1) Composite slab [1]

The decking performs a number of roles and is an important part of the structural system [1].

1. Profiled sheeting acts as stay-in place formwork.
2. Offers an immediate working plat form.
3. Acts as slab reinforcement.
4. Saves up to 30 % of concrete material.
5. Accommodates service decks.
6. Makes easy transportation and installation.

Many advantages can be obtained from composite concrete with corrugated sheet. These advantages are light weight, decrease in dimensions of foundation, decrease in dimensions of members of structure and no need for forms. Steel section does not resist fire; therefore it should be covered by a material which has resistance to fire for no less than 3-hours [2] .

This type of slabs consists of three materials: steel section, concrete section and methods of connection. Many advantages are gained when connectors are used to attach the external plate to the concrete [3]:

1. Stud or bolt connectors will transfer load to the core of the concrete section.
2. Stud or bolt connectors provide vertical and horizontal resistance to forces developed at concrete-plate interface.
3. High resistance to any effect of chemical contact or weather change.
4. Easy to apply, without surface preparation, and no delay time is required after fixing.
5. Low cost of connectors.

Together with these advantages, few disadvantages are encountered,

1. The drilling process needs skilled workers and extra attention.
2. Extra calculation is required to obtain the total number of connectors to be provided.

The calculation of the bending resistance is based on idealized fully plastic behavior. According to test results, this bending capacity hardly ever reaches normal design conditions because the shear failure is mostly preceding [4].

In the composite action, the horizontal shear transfer mechanism (resistant force to interface slip) is provided by a combination of the followings:

1. Chemical bond and friction at the interface of the deck and the concrete.
2. Mechanical interlock between the steel deck and the concrete slab or frictional interlock for profiles in a re-entrant form.
3. End anchorage in the form of stud bolts or deformation of the ribs.

2. Experimental Work

Twelve specimens of composite slab are cast. Characteristic of each slab is shown in **Table (1)** which is divided into three groups. Steel (Iron) decks are introduced to withstand tensile stresses and covered with concrete to withstand compressive stresses. They have dimensions, as shown in **Fig.(2)** and **Picture (1)**. Two lengths 1300mm for 6 specimens and 1600mm for 6 specimens are used.

Table (1) Characteristics of the tested slabs

Group No.	Type	Slab No.	Length (mm)	Width (mm)	Depth (mm)	Fcu (MPa)	Notation
1	**RS**	1	1600	300	90	36.8	*Cast without additional steel bars*
		2	1600	300	90	36.8	
		3	1300	300	90	36.8	
		4	1300	300	90	36.8	
2	**RLB**	5	1600	300	90	36.8	*Cast and strengthened by adding steel bars*
		6	1600	300	90	36.8	
		7	1300	300	90	36.8	
		8	1300	300	90	36.8	
3	**RSR**	9	1600	300	90	36.8	*Cast with increased shear resistance by shear reinf.*
		10	1600	300	90	36.8	
		11	1300	300	90	36.8	
		12	1300	300	90	36.8	

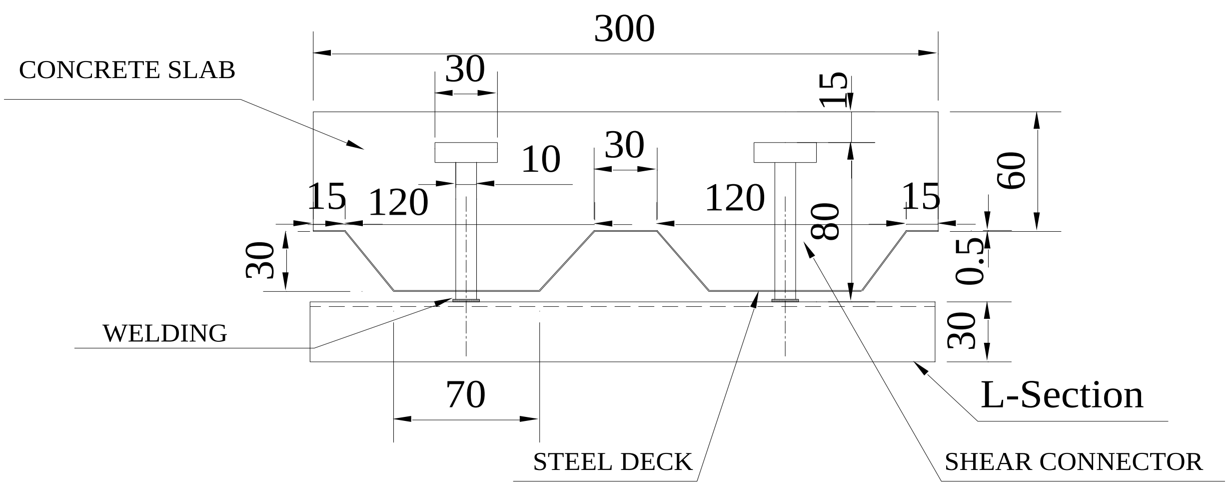


Figure (2) Dimensions of steel deck

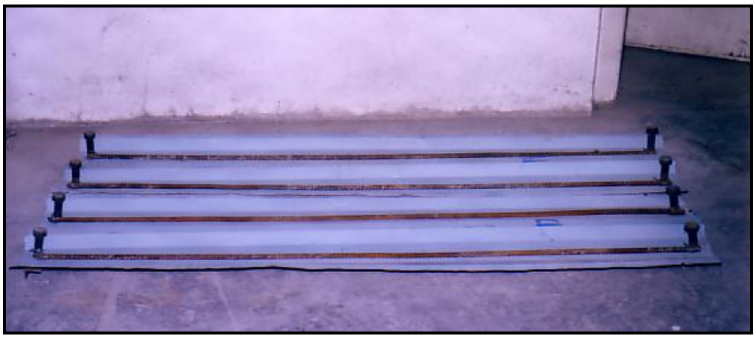
Picture (1) Shape of steel deck

The yield strength is determined in the laboratory of materials, College of Engineering, Al-Mustansiriya University, and the average result is 350 MPa as yield strength and the average concrete cubic strength of (36.8 MPa) at 28 days. Steel angle is used to act as beam section and to attach shear connectors. In laboratory, these angles are used to fix with the supports of the machine of test.

Dimensions of angle used are L (30*30*3 mm) and the length of the angle is equal to the width of the slab (i.e. equal to 300 mm). In these specimens, bolt connectors (galvanized) are used. These bolts attach the steel angles by welding, see **Fig.(2)**.

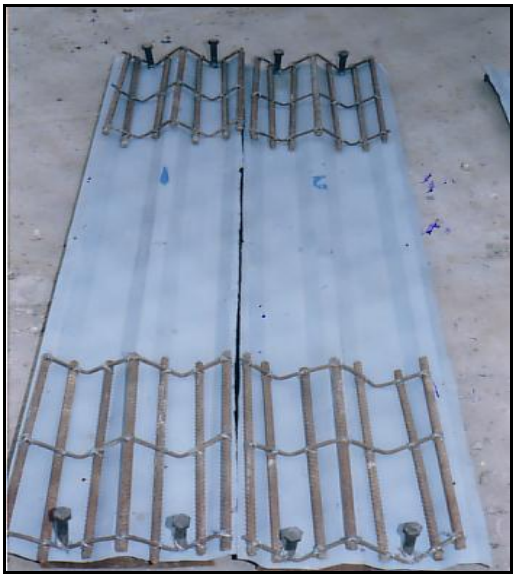
First group: Four specimens of composite slab were casted without additional steel bars (RS), as shown in **Fig.(2)** and **Picture (1)** above.

Second group: Four specimens of composite slab were casted and strengthened by adding longitudinal bars (RLB). In four specimens only, steel bars are used by adding one bar in each deck. These bars are 12.5mm in diameter and the average yield strength is 450 MPa. **Picture (2)** shows steel deck with the addition of longitudinal bars.



Picture (2) Steel deck with longitudinal bars (RLB)

Third group: Four specimens of composite slab were casted with an increase in shear resistance by using shear reinforcement at the ends of the composite slabs with length equal to the quarter of the length of these slabs (RSR), as shown in **Picture (3)**. It consists of longitudinal straight bars parallel to the length of slab and bent bars perpendicular to the length of the slab for four specimens to improve shear resistance. The longitudinal straight bars are 12.5mm in diameter and the average yield strength is 450 MPa. The bent bars are 10 mm in diameter and the average yield strength is 450 MPa. These bars are connected together to form a shape, as shown in **Picture (3)**.



Picture (3) Steel deck with shear reinforcement (RSR)

3. Ultimate Load Capacity of Composite Slabs

Two-point loads are applied to these slabs. **Figures (3)** and **(4)** shows magnitude and positions of these two point load shear force diagram and bending moment diagram.

Experimental results Ultimate load capacity of the tested slabs at 28 days is shown in **Table (2)**. The ultimate load capacity of slabs (RLB) is larger than that of slabs (RS) and (RSR) because of the increase in tension by adding longitudinal bars whose diameter is (12.5mm) at each deck. The table and the figure mentioned above show ultimate load capacity of slabs (RSR) close to ultimate load capacity of slabs (RS) (i.e. using shear reinforcement does not increase the ultimate load capacity). It can be concluded that slabs with longitudinal bars (RLB) will give high increase in ultimate load capacity, and use of shear reinforcement does not increase the ultimate load capacity.

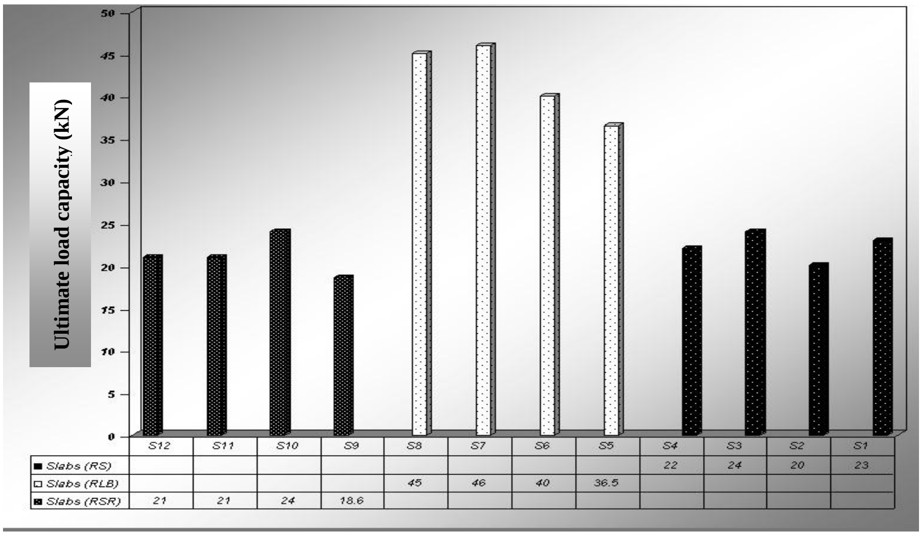


Figure (3) Ultimate load capacity of the tested slabs

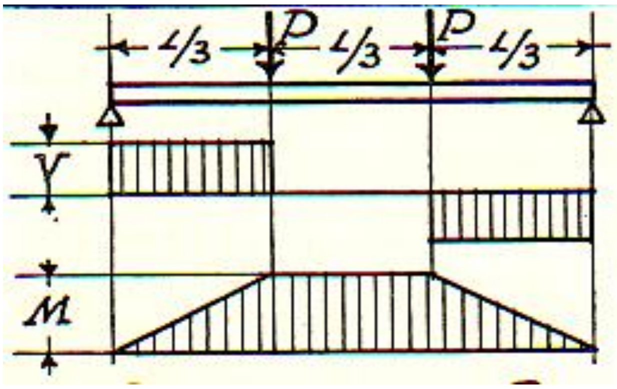


Figure (4) Shear force and bending moment diagrams
each Reactions = P, Max. V = P, Max. M = pl/3

Table (2) Test Results, maximum values of load capacity for tested slabs

Slab	Type	Length (mm)	Ultimate load capacity (kN)
S_1	RS	1600	23
S_2	RS	1600	20
S_3	RS	1300	24
S_4	RS	1300	22
S_5	RLB	1600	36.5
S_6	RLB	1600	40
S_7	RLB	1300	46
S_8	RLB	1300	45
S_9	RLR	1600	18.6
S_{10}	RSR	1600	24
S_{11}	RSR	1300	21
S_{12}	RSR	1300	21

The mean ratios of ultimate load capacity for the strengthened slabs (RLB) to reference slabs (RS) are (1.78) and (1.98) for slabs which have lengths equal to (1600 mm) and (1300 mm), respectively, see **Table (3)**. Then, the ultimate load capacity of slabs (RLB) is more than that of the ultimate load capacity of slabs (RS), which reaches about (78%) and (98%) for slabs which have lengths equal to (1600 mm) and (1300 mm), respectively.

Table (3) Ratio of mean maximum values of Slabs (RLB) to (RS)

Slab			Ultimate load capacity (kN)	Slab		Ultimate load capacity (kN)	Ratio of mean values of (RLB) to (RS) Ultimate load capacity
1	RS	1600	23	5	RLB	36.5	**1.78**
2	RS	1600	20	6	RLB	40	
3	RS	1300	24	7	RLB	46	**1.98**
4	RS	1300	22	8	RLB	45	

The mean ratios of ultimate load capacity for the slabs (RSR) to reference slabs (RS) are (0.99) and (0.92) for the slabs which have lengths equal to (1600mm) and (1300mm), respectively, see **Table (4)**. Then, the ultimate load capacity of slabs (RSR) are less than the ultimate load capacity of slabs (RS), by about (1%) and (8%) for slabs which have lengths equal to (1600 mm) and (1300 mm), respectively. These ratios are small values and can be neglected and the use of shear reinforcement does not increase the ultimate load capacity.

Table (4) Ratio of mean maximum values of Slabs (RSR) to (RS)

Slab			Ultimate load capacity (kN)	Slab			Ultimate load capacity (kN)	Ratio of mean values of Ultimate load capacity of (RSR) to (RS)
1	RS	1600	23	9	RSR	1600	18.6	**0.99**
2	RS	1600	20	10	RSR	1600	24	
3	RS	1300	24	11	RSR	1300	21	**0.92**
4	RS	1300	22	12	RSR	1300	21	

The mean ratios of ultimate load capacity of slabs with lengths equal to (1300mm) to (1600mm) are (1.07), (1.19) and (0.986) for slabs (RS), (RLB) and (RSR), respectively, see **Table (5)**. Ultimate load capacity of slabs which has length equal to (1300mm) is more than the ultimate load capacity of slabs which has length equal to (1600mm). This is obvious in slabs (RLB) because the values of ultimate load capacity are large and the differences in values of ultimate load capacity between slabs which have lengths equal to (1300mm) and (1600mm) are large too. Then, the ultimate load capacity of slabs (RLB) increase (19%) when the length of these slabs reduces from (1600mm) to (1300mm).

Table (5) Ratio of mean maximum values to show the effect of lengths for Slabs (RS), (RLB) and (RSR)

Slab			Ultimate load capacity (kN)	Slab			Ultimate load capacity (kN)	Ratio of mean values of Ultimate load capacity of length of slabs (1300mm) to (1600mm)
1	RS	1600	23	3	RS	1300	24	**1.07**
2	RS	1600	20	4	RS	1300	22	
5	RLB	1600	36.5	7	RLB	1300	46	**1.19**
6	RLB	1600	40	8	RLB	1300	45	
9	RSR	1600	18.6	11	RSR	1300	21	**0.986**
10	RSR	1600	24	12	RSR	1300	21	

But, the increase of mean value of ultimate load capacity of slabs (RS) reaches about (7%), when the length of these slabs reduces from (1600mm) to (1300mm). This difference is small value because values of ultimate load capacity are small and the differences in values ultimate load capacity between slabs which have lengths equal to (1300mm) and (1600mm) are small so that the ultimate load capacity of slab (S_1) is larger than slab (S_4) which has length equal to (1300mm). The mean values of ultimate load capacity of slabs which have length equal to (1300mm) for slabs (RSR) are smaller than the values of slabs which have length equal to (1600mm) by about (1.4 %) because slab (S_{10}) is larger than slabs (S_{11}) and (S_{12}).

4. Conclusions

1. Ultimate load capacity of composite slabs (RS) and composite slabs with longitudinal bars (RLB) increases (7%) and (19%), respectively, when the length of these slabs reduce from (1600mm) to (1300mm).

2. Composite slab with longitudinal bars (RLB) gives higher ultimate load capacity. Ultimate load capacity of composite slabs with longitudinal bars (RLB) is more than composite that of slabs (RS), the latter reached by about (78%) and (98%) the increases for slabs which have length equal to (1600mm) and (1300mm), respectively.

3. Composite slab with shear reinforcement (RSR) has not shown increase in the ultimate load capacity.

4. Using the shear connectors to attach the steel plate to the concrete is very successful and efficient in developing the composite action between the concrete slabs and the steel plates up to failure.

5. Failure of these composite slabs (RS), (RLB) and (RSR) is found similar to over reinforced section because concrete reaches its compressive strength before the corrugated sheet reaches its tensile strength.

5. References

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4. ***"Building Code Requirements for Structural Concrete"***, (BS 5950-82), Part 4, British Standards Institution, 1982.

List of Abbreviation

RLB: Composite slab with longitudinal bars

RS: Composite slab (reference slab)

RSR: Composite slab with Shear Reinforcement

S_1: Composite slab (reference slab) (RS), Length =1600mm

S_2: Composite slab (reference slab) (RS), Length =1600mm

S_3: Composite slab (reference slab) (RS), Length =1300mm

S_4: Composite slab (reference slab) (RS), Length =1300mm

S_5: Composite slab with longitudinal bars (RLB), Length =1600mm

S_6: Composite slab with longitudinal bars (RLB), Length =1600mm

S_7: Composite slab with longitudinal bars (RLB), Length =1300mm

S_8: Composite slab with longitudinal bars (RLB), Length =1300mm

S_9: Composite slab With Shear Reinforcement (RSR), Length =1600mm

S_{10}: Composite slab With Shear Reinforcement (RSR), Length =1600mm

S_{11}: Composite slab With Shear Reinforcement (RSR), Length =1300mm

S_{12}: Composite slab With Shear Reinforcement (RSR), Length =1300mm