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Mohaned Mohy El-deen Hassan
Benha University, Marshal.Mohaned24@gmail.com

Khaled Abdullah Gharib
Benha University, Khaled.gharib@feng.bu.edu.eg

Hanan Hussain altobgy
Benha University, hanan.altobgy@feng.bu.edu.eg

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Cover Page Footnote

Eltobgy et al.: Influence of Concrete Jacketing on the Performance of Steel Columns under Blast induced Progressive Collapse

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Experimental and Analytical Study on Shear Bond Behaviour of Lightweight Concrete Composite Deck Slab with Shear Connectors

Mohaned M. Hassan [1], Khaled A. M. Gharib[2], Hanan H. Eltobgy [3]
[1] Postgraduate student, Civil Department, Faculty of Engineering (Shoubra), Benha University, Giza, Egypt
[2] Lecturer (PhD), Civil Department, Faculty of Engineering (Shoubra) , Benha University, Giza, Egypt
[3] Professor of Steel Structures, Civil Department, Faculty of Engineering (Shoubra), Benha University, Giza, Egypt
*Corresponding author's email: marshal.mohaned24@gmail.com Hanan.altobgy@feng.bu.edu.eg , Khaled.gharib@feng.bu.edu.eg

***Abstract*- This study investigates the bond strength between lightweight concrete and steel elements in composite deck slabs, with a focus on enhancing bond performance through the use of shear connectors. The primary objective was to improve the interface behaviour between lightweight concrete and steel corrugated sheets by introducing shear connectors between the composite slab and supporting steel beams. Both experimental and analytical methods were employed. Experimentally, twelve lightweight concrete specimens were fabricated and divided into two groups: one without shear connectors and the other with shear connectors. Each group was further classified into specimens with long and short spans. These specimens were subjected to static and cyclic loads to evaluate their performance. The findings revealed that incorporating shear connectors improved bond strength by 20% to 78% compared to specimens without connectors. Additionally, short-span specimens exhibited 20-90% higher flexural strength than long-span specimens. The sliding movement was reduced by 20-40% in slabs with shear connectors, demonstrating enhanced ductility and sliding resistance. Analytical validation was performed using international codes, and the results aligned well with the experimental outcomes. The shear bond properties of lightweight composite slabs were determined using the semi-empirical m-k method, as specified in EN 1994-1-1:2004, confirming the reliability of the findings.**

This study underscores the significant advantages of incorporating shear connectors in lightweight composite slabs, providing valuable insights for optimizing their structural performance.

***Keywords*- Composite Deck Slab; Lightweight Concrete; Shear Connectors; Profiled Steel Sheet; Shear Bond Behavior; m-k method.**

I. INTRODUCTION

Composite floor systems composed of cold-formed profiled steel decking and lightly reinforced concrete, are commonly used in building construction due to their strong structural performance and economic benefits. These advantages include being lightweight and enabling faster construction. The composite deck slab relied on the bond strength between the concrete and the steel sheet. Therefore, previous studies were carried out to investigate the behavior of the composite deck slabs with the affecting parameters. Researchers have studied reinforced concrete. Some studied converting fine aggregate into rubber crumbs that enhance the bond between the concrete and steel sheet, Bashar S. Mohamed et al. [1]. Some of them also believed that effective engineering cement compounds are available for concrete, K.M.A. Hossain et al. [2].

It was also seen that the steel sheet differs in terms of two reasons, one of which is the thickness of the steel sheet and the difference between 0.8 mm and 1.2 mm, S.P. Siddh et al. [3]. The other reason is the height of the concrete sheet, 55 mm and 70 mm. Héctor Cifuents and Fernando Medina et al. [4]. Some researched the change in the embossments present on the existing cold-formed steel surface, V. Mari-Muthu et al. [5]. Other researchers studied the effect of changing the embossments to investigate the bond between the concrete and the steel sheet, Namdeo Adkuji Hedaoo et al. [6].

Some researchers studied the terms and conditions of each code, such as the European code [7], Héctor Cifuentes and Fernando Medina [8], Thomas N. Salonikios et al. [9], and Saravanan M. et al. [10]. Recently, it has been considered to use shear connectors between concrete and steel sheets such as Shimming Chen and Xiaoyu Shi [11], Sayan Sirimontree [12], and Hanan H. Eltobgy [13].

Research Significance

As mentioned in the introduction, numerous studies have examined the shear bond behavior of composite deck slabs. Still, the effect of shear connectors between the deck slab and the supporting beam has often been overlooked. This paper also investigates the impact of lightweight concrete on composite deck slabs' shear bond capacity in the presence of shear connectors. This research compares the structural performance of composite slabs with and without shear connectors. Both experimental and theoretical analyses will focus on shear and moment resistance, load-displacement response, failure modes, load-slip behavior, ductility, capacity, and steel-concrete shear bond resistance.

II. EXPERIMENTAL PROGRAM

A. Lightweight Concrete

Six concrete cube samples were prepared for load testing following the Euro Code 4. Each cube measures 15.8 cm x 15.8

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cm x 15.8 cm and was cast in the laboratory. The following materials were included in the concrete mix:

Sand: Locally sourced, well-graded sand.

Coarse Aggregate: Locally sourced, well-graded coarse aggregate.

Cement: CEMI 52.5N cement, complying with the Egyptian Code standards.

Silica Fume: Locally sourced silica fume.

Super plasticizer: Master Rheo-build 3060.

Pumice Stone: Inspired by Karthika R.B. [14].

Pumice stone is an essential component for creating lightweight concrete capable of withstanding high pressures. As shown in Figure 1, this environmentally friendly material has a specific gravity of 1.05. Due to its higher water absorption than typical aggregate, pumice stone was soaked in water for 24 hours before use. It served as a size substitute for the aggregate in the mix.

Figure 1. Pumice Stone

The concrete mixture was prepared according to the components shown in Table 1 for one cubic meter. The design of the admixture was made from different trial mixes and tests to adjust the content of the concrete mix to get lightweight concrete with accepted strength according to the specification of Euro code 4.

Table 1 Lightweight Concrete mix properties for a one-meter cube

Water (kg)	Sand (kg)	Coarse Agg. (kg)	Cement (Kg)	Pumice (kg)	Super-plasticizer (L)	w/c raito	Silica Fume (Kg)
137.5	400	400	430	150	10	0.32	30

B. Lightweight Concrete Properties

All samples were poured simultaneously from a single mixer and tested for compressive strength at 7, and 28 days to assess the concrete's performance with this admixture. Table 2 presents the laboratory results for the lightweight concrete, including its density and compressive strength at both testing intervals. The required crushing stresses for composite slab surfaces permitted by the European Code were reached through experimentation. The permitted crushing strength was not less than 250 kg/cm2, and the density was less than 1950 kg/m3.

Table 2 Lightweight concrete results

No.	Crushing Days	Density (Kg/m^3)	Load (Kg)	Crushing Stress F_c (kg/cm^2)
C1	7	1862	74	296
C2	7	1887	70	280
C3	7	1858	64	256
C4	28	1915	103	413
C5	28	1915	105	422
C6	28	1941	100	402

C. Shear Connectors

The composite action between the deck slab and the supporting steel beam was achieved using UPN shear connectors. In compliance with Euro code [7], UPN 100 shear connectors were used, each measuring 12 cm in length and made of steel grade 37. These connectors were welded to the top flange of the HEA 180 supporting beam, as illustrated in Figure (2). Afterward, the deck's steel sheet was attached to the top flange of the HEA 180. The shear connectors were strategically placed between the deck slab and the supporting beam to ensure the composite action between steel beam and deck slab and to improve the shear bond.

Figure 2 Arrangement of shear connectors

D. Profiled Metal Deck

Profiled metal deck used in this research is shown in Figure (3). It measures 95 cm in width and 55 mm in height, with its mechanical properties listed in Table 3.

Table 3 Mechanical Properties of the Profiled Metal Deck

	Type	Profile 55mm	Type	Profile 55mm
Mechanical Properties	Thickness (mm)	0.7	Ultimate Strength (F_u) N/mm^2	394
	Weight (kg/m^2)	9.35	Tensile Strength (N/mm^2)	366
	Inertia moment (I_x) mm^4	3.24 x 10^9	Elongation	30%
	Width (b) mm	950	Hardness HRB	61
	Yield Strength (f_y) N/mm^2	302	ADH test	Pass

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Figure 3 Profiled Metal Deck

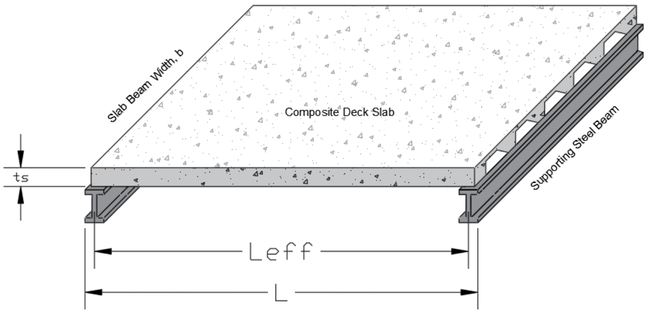


Figure 4 Dimension of composite deck slab

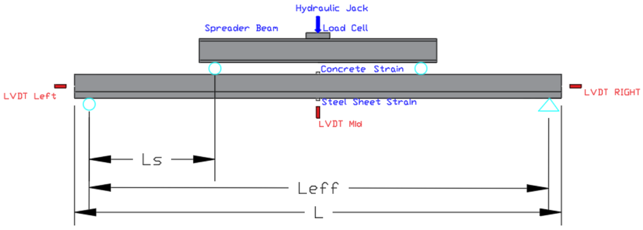


Figure 5 Test setup and installation

E. Reinforcement bars of composite slab

According to Euro code [7], steel reinforcement bars 5φ10 /m (with yield strength, fy, 36 kN/cm²) are used in both directions to resist shrinkage and temperature effects.

F. Test Setup

A total of twelve specimens were cast in the laboratory using lightweight concrete, following these procedures:

The steel deck and reinforcement were prepared, with the reinforcement lifted from the steel deck using plastic spacers. Wooden formwork was constructed for each specimen to facilitate casting. For specimens with shear connectors, the connectors were welded to the top flange of the supporting beams, after which the steel decking was attached to the beams.

The specimens were divided into four groups:

a) Short span without shear connectors
b) Short span with shear connectors
c) Long span without shear connectors
d) Long span with shear connectors

Figures (4 - 8) illustrate the arrangement of the specimens in the laboratory. The first specimen in each group was tested under static loading, while the remaining two specimens were subjected to cyclic loading. Table 4 details the grouping of the specimens.

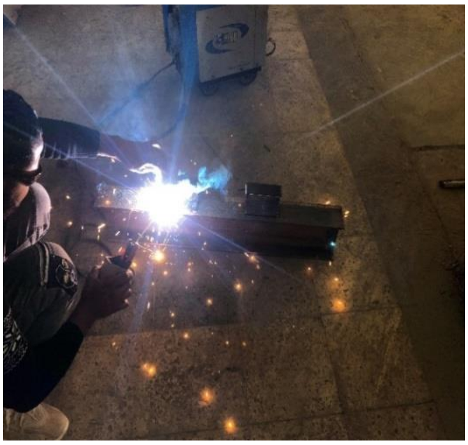
L_s is the shear span at each specimen.

L_{eff} is the effective span from the center line for each supporting element.

Table 4 Dimensions and detail of composite deck slab

Groups	Specimens	L mm	L_{eff} mm	L_s mm	t_s mm	b mm	Steel Sheet depth	Cyclic load	Shear Connectors
A	S1	1500	1320	330	160	950	55	No	No
	S2							Yes	No
	S3							Yes	No
B	S4							No	Yes
	S5							Yes	Yes
	S6							Yes	Yes
C	S7	3000	2820	805				No	No
	S8							Yes	No
	S9							Yes	No
D	S10							No	Yes
	S11							Yes	Yes
	S12							Yes	Yes

a) Shear Connectors Arrangement



b) Welding Shear connectors

Figure 6 Arrangements of Shear Connectors and Supporting Steel Beam

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Figure 7 Specimen before pouring concrete

Figure 8 Specimen after pouring concrete

G. Test Procedure

The specimens were tested in the laboratory. The beams are simply supported. A hydraulic loader with a capacity of 500 kN applied the load, which was linearly distributed across the width of the deck slab.

Three types of deformations were measured using Linear Voltage Displacement Transformers (LVDTs), as shown in Figure 5. One LVDT was placed at the bottom center of the deck slab to measure the vertical displacements at the mid-span, and two LVDTs (one on each side) were positioned at the ends of the deck slab to measure the relative slip between the concrete topping and the profiled steel. Additionally, two strain gauges were used: One strain gauge measured the concrete strain and was placed at the top of the deck slab. The other strain gauge measured the steel sheet strain and was positioned at the bottom of the deck slab. Both strain gauges were attached at the mid-span of the deck slab. Figure 5 illustrates the layout and locations of the strain gauges and LVDTs on the composite deck slab. All LVDTs and strain gauges were connected to a data acquisition system linked to a personal computer to record data during the testing process.

H. Loading Procedure

According to Euro code 4 [7], the specimens in each group were loaded as follows:

a. Preliminary Static Test

The first specimen in each group was subjected to a static load to determine the failure load. The load was applied by controlling displacement at 0.25 mm/min until the slab reached its failure load.

b. Final Test

The remaining two specimens in each group were subjected to cyclic loading. The final test for the composite deck slabs was performed into two stages: In the first stage, the slabs underwent cyclic loading. In the second stage, the slabs were loaded to failure by gradually increasing the load. Each load cycle was conducted in forced load mode.

i) Initial Test:

The specimens were subjected to 5000 cycles of loading, applied over 3 hours. The cyclic load ranged from 20% to 60% of the collapse load, which was determined from the static load test of the first specimen in each group. The loading rate was set at 0.52 cycles per second, and data acquisition was conducted at a frequency of 10 Hz.

ii) Subsequent Test:

After completing the initial cyclic test, the specimen was subjected to a static load. The load was gradually increased, ensuring that failure did not occur in less than one hour.

iii) Results Recorded:

After testing all the specimens, the following data were recorded:

- Deflection at the slab's mid span.
- Slippage between the concrete and the steel sheet on the right side.
- Slippage between the concrete and the steel sheet on the left side.
- Strain in the steel sheet.
- Strain in the concrete slab.
- Strain in the reinforcement bars.

III. Results and Discussions

A. Mode of Failure and General Observation

The loading tests on the specimens demonstrated similar qualitative mechanical behavior, indicating effective interaction between the steel sheets and lightweight concrete. this interaction was notably reduced in specimens without shear connectors, while a significant bond was observed in those with shear connectors. This disparity was reflected in the specimens' collapse loads.

As the load increased, it became evident that the bond between the concrete and steel sheet weakened, resulting in separation near the loading points. Additionally, slippage between the concrete and steel sheet was observed; this was less pronounced in specimens with shear connectors and more significant in those without. Ultimately, the composite slab failed as the deflection of the specimens increased. Upon reaching the collapse load, vertical cracks appeared in the samples under load, as illustrated in Figures 9 and 10.

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a) Specimen S1

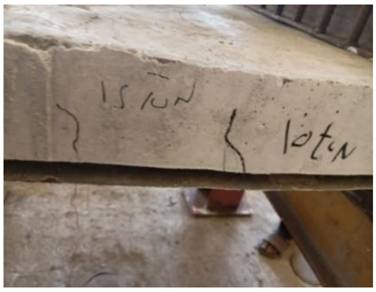
b) Specimen S4

c) Specimen S7

d) Specimen S10

Figure 9 Failure of Specimens under Static load

b) Specimen S3



c) Specimen S5

d) Specimen S6

e) Specimen S8

f) Specimen S9

a) Specimen S2

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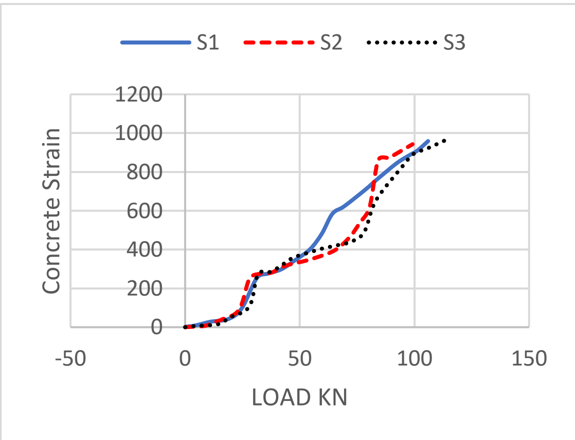
g) Specimen S11

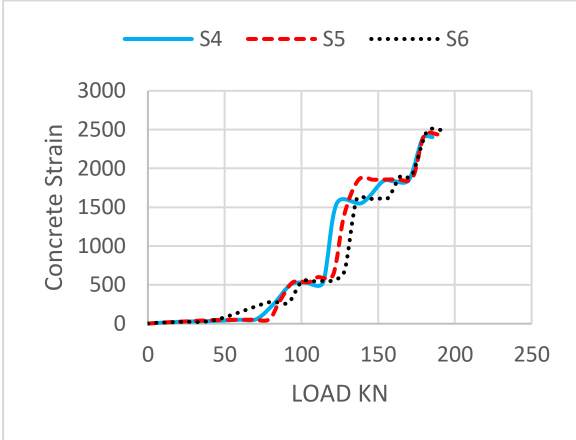
h) Specimen S12

Figure 10 Failure of specimens under Cyclic load test

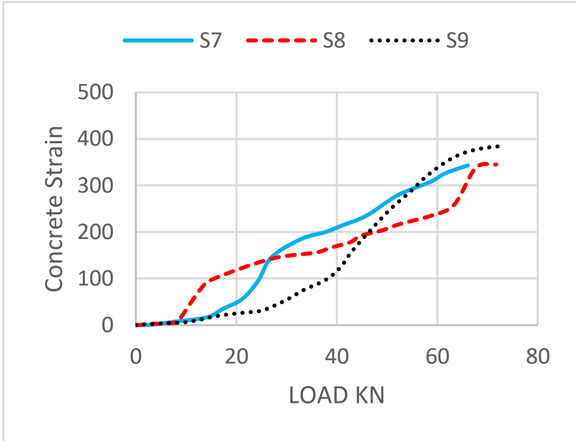
B. Strain Development in Concrete Surfaces, Steel Sheets and Reinforcement Bars

Figures 11a and 11b illustrate the relationship between concrete strain and the applied loads for short-span specimens, both with and without shear connectors. In contrast, Figures 11c and 11d present the same relationships for long-span specimens. It was observed that short-span specimens exhibited greater stress resistance than their long-span counterparts. Furthermore, all specimens equipped with shear connectors supported higher loads rather than those without. Specimens with shear connectors demonstrated significantly higher ductility and energy absorption capabilities compared to those lacking these connectors, which tended to be more brittle. For the cyclic load test, a specimen showcasing the load behaviour versus concrete strain to get the experimental result is presented in Figure 11e.

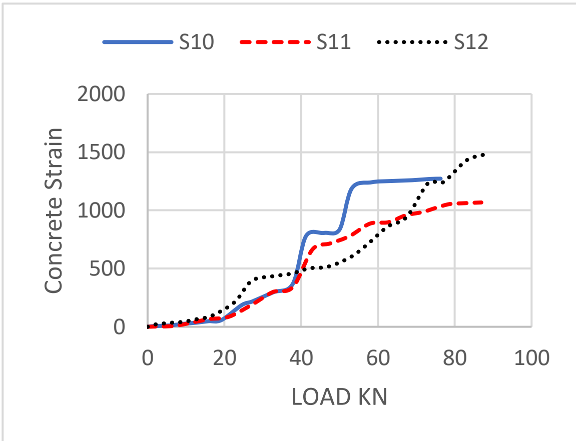




b) Short-span Specimens with Shear Connectors



c) Long-span Specimens without Shear Connectors



d) Long-span Specimens with Shear Connectors

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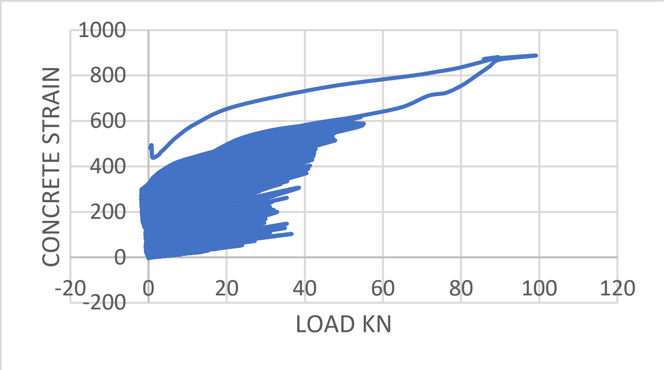
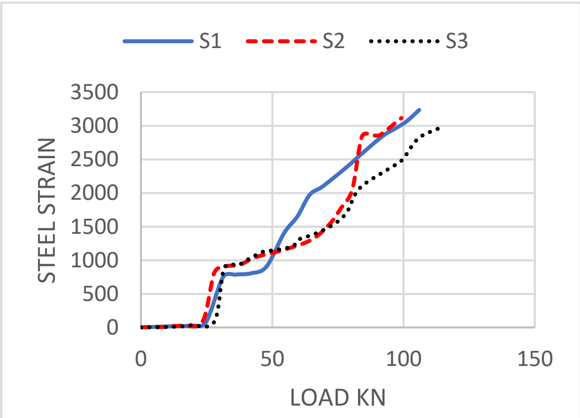


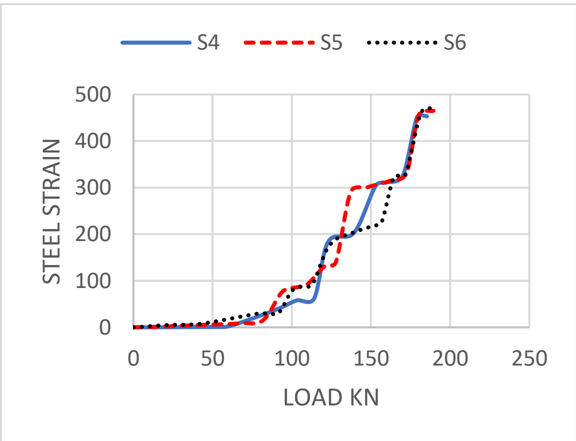
e) S2 Cyclic load Test

Figure 11 Concrete Strain Developments

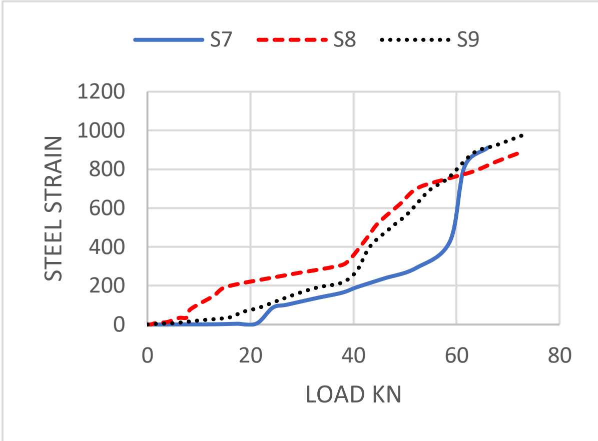
One of the critical components in the composite deck slab is the profiled steel sheet, for which a strain gauge was installed at the bottom of each sheet. It was noted that specimens with shear connectors exhibited greater stress-bearing capacity, while the lightweight concrete remained bonded, only slipping under significantly higher loads compared to specimens without shear connectors. Additionally, short-span specimens performed better than long-span specimens, as illustrated in Figure 12. For the cyclic load test, a specimen showcasing the load behavior versus steel strain to get the experimental results is presented in Figure 12e.



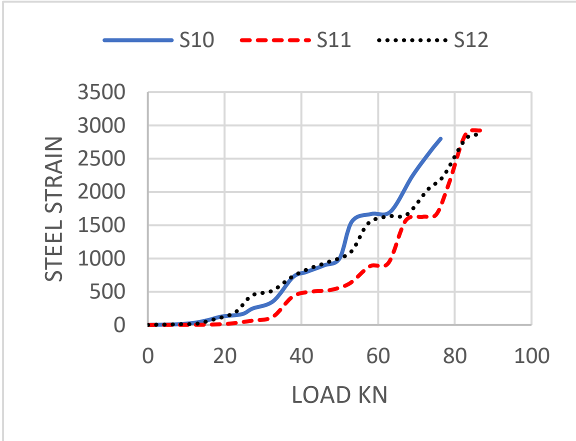
a) Short-Span Specimens without shear connectors



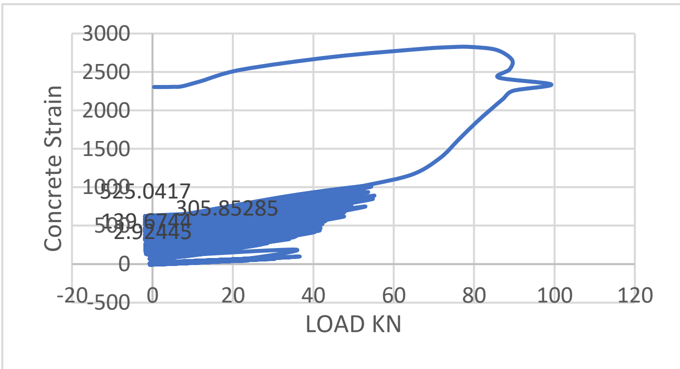
b) Short-Span Specimens with shear connectors



c) Long-Span Specimens without shear connectors



d) Long-Span Specimens with shear connectors



e) S2 Cyclic load Test

Figure 12 Steel Sheet Strain Developments

Figure 13 illustrates the relationship between the applied load and the strain in the reinforcement bars for short and long spans, with and without shear connectors. Specimens equipped with shear connectors can support greater loads compared to

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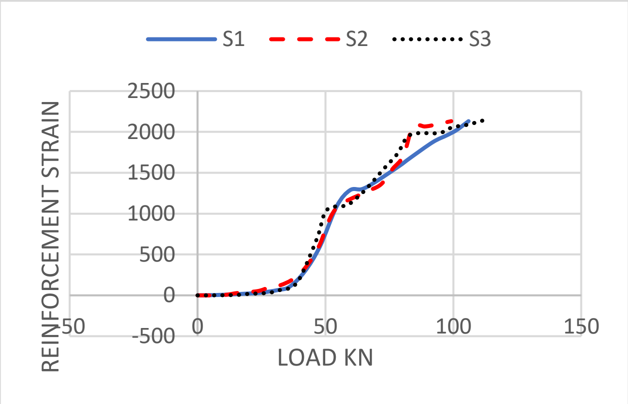
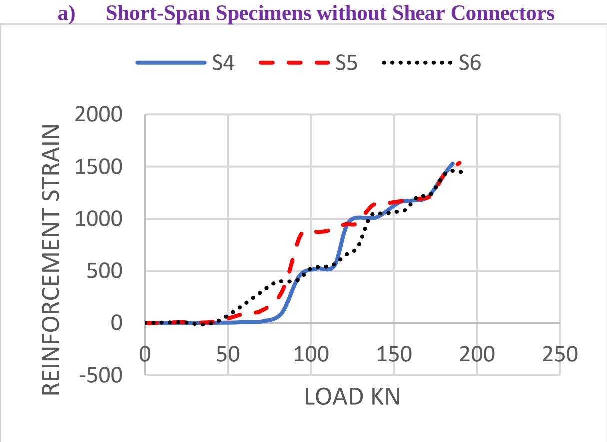
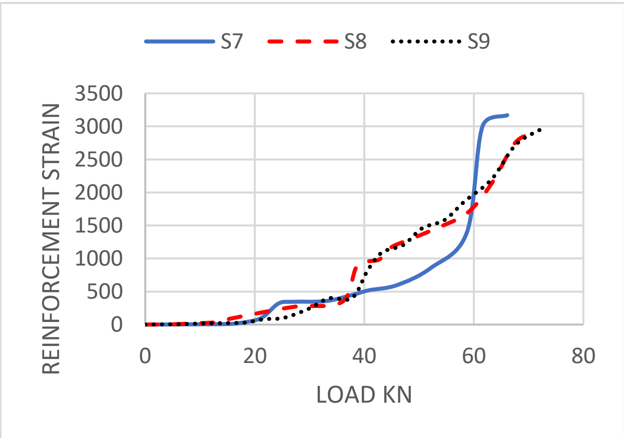
those without shear connectors. Additionally, the inclusion of rebar in the samples enhances their load-bearing capacity and protects the concrete surface from cracking, thereby increasing its overall hardness. The concrete in long-span and short-span samples exhibited greater strength, enabling them to withstand higher loads.



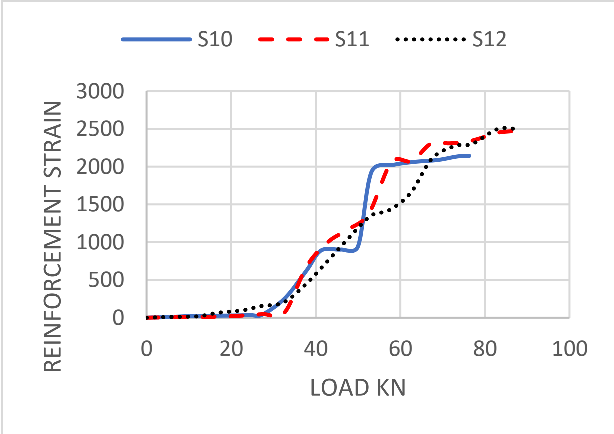
a) Short-Span Specimens without Shear Connectors



b) Short-Span Specimens with Shear Connectors



c) Long-Span Specimens without Shear Connectors



d) Long-Span Specimens with Shear Connectors

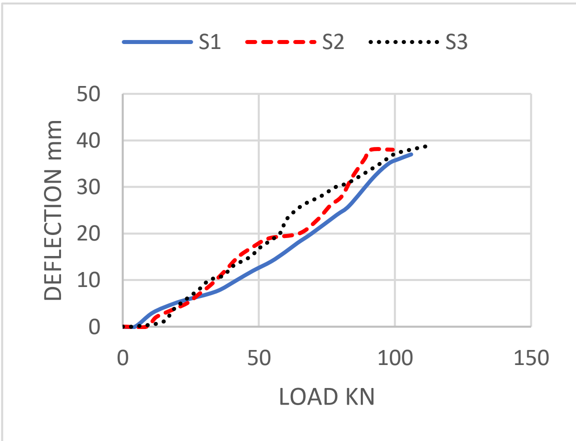
Figure 13 Reinforcement Bars Strain Developments

C. Load / Mid-span deflection response

Figure 14 depicts the relationship between the applied load and the mid-span deflection of long and short lightweight composite slabs, both with and without shear connectors between the deck slab and the supporting beam. Specimens S1, S4, S7, and S10 were tested under monotonic loading, while specimens S2, S3, S5, S6, S8, S9, S11, and S12 underwent cyclic loading.

It was observed that slabs subjected to cyclic loading exhibited lower ultimate loads than those tested monotonically. This reduction can be attributed to the cyclic loading diminishing the bond between the steel sheet and the concrete topping, resulting in decreased composite action. The impact of cyclic loading on mid-span deflection was observed due to the displacement in the specimens at the end of the cyclic test, which was followed a reduction in stiffness and an increase in the number of cycles applied. The displacement was primarily caused by the loss of the shear bond between the concrete and the steel sheet, as shown in Figure 14.

Moreover, specimens with shear connectors were able to sustain larger loads before reaching maximum deflection compared to those without shear connectors. The presence of shear connectors enhanced the shear bond for short-span slabs by approximately 30% and for long-span slabs by about 80%.



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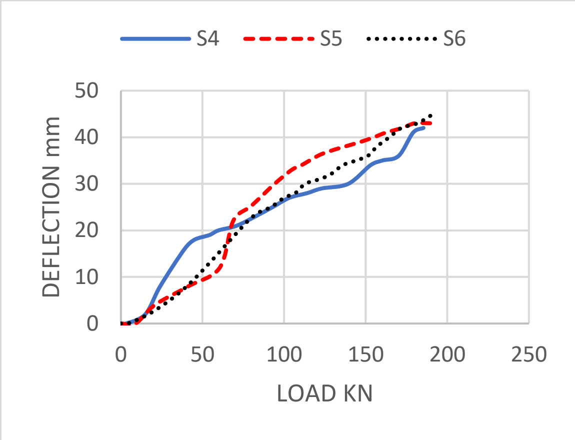
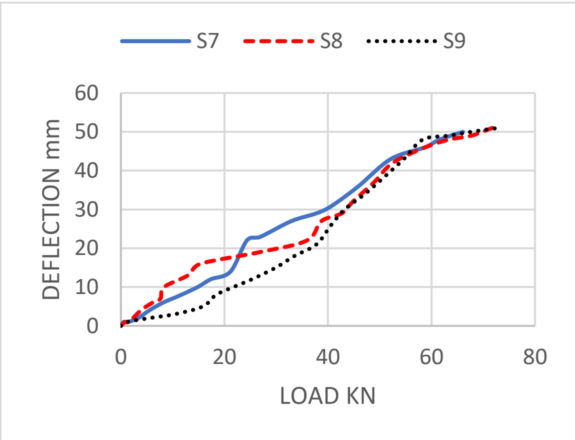
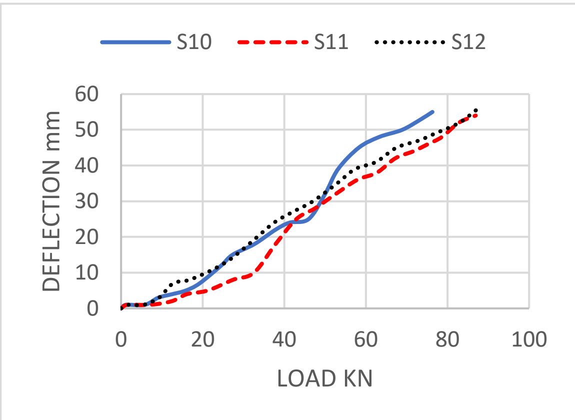
a) Short-Span Specimens without Shear Connectors



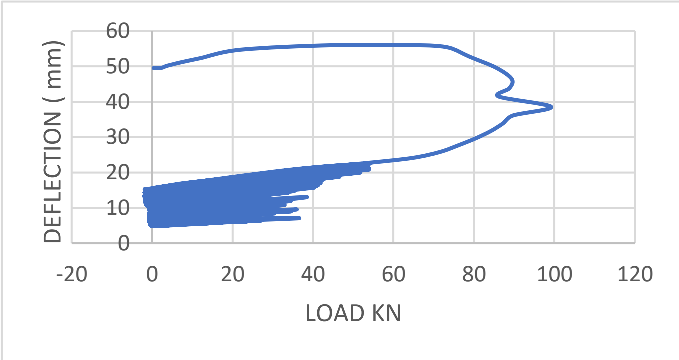
b) Short-Span Specimens with Shear Connectors



c) Long-Span Specimens without Shear Connectors



d) Long-Span Specimens with Shear Connectors

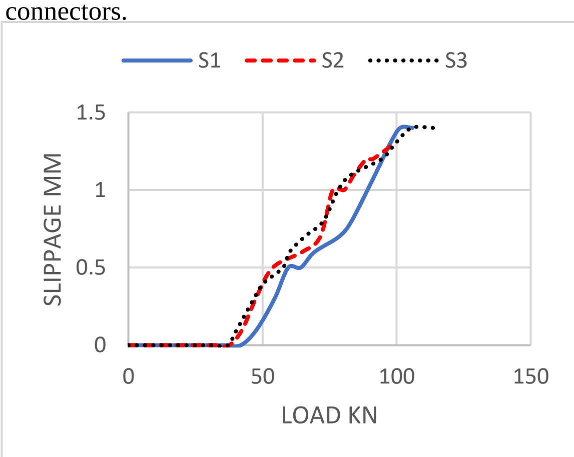


e) S2 Cyclic load test

Figure 14 Load-Deflection Relationships

D. End Slippage Results

Measured values obtained from LVDT from the right side are nearly equal to values obtained from the left side, so only one value was taken, and the second was ignored. At the end of the test of all specimens, the presence of the slip is noticed in all specimens between concrete and steel sheets. It is noticed that the slip is less in the presence of shear connectors in the specimen. On the contrary, in the absence of them, the slip is greater. The results of the specimens showed that the specimens with a short span showed greater resistance to slippage than specimens with a longer span before slipping occurred. It also showed that specimens with shear connectors between the deck slab and supporting beam have greater resistance to load and less slip than specimens without shear connectors at failure load, as shown in Figure 15. Slippage begins between the concrete and the steel sheet if the load reaches 25%- 40% of the collapse load. The increase in slippage resistance between the specimens with shear connectors and the specimens that did not contain shear connectors was an increase of 20%-40% to bear much higher loads than the samples that did not contain shear connectors.



a) Short-Span Specimens without Shear Connectors

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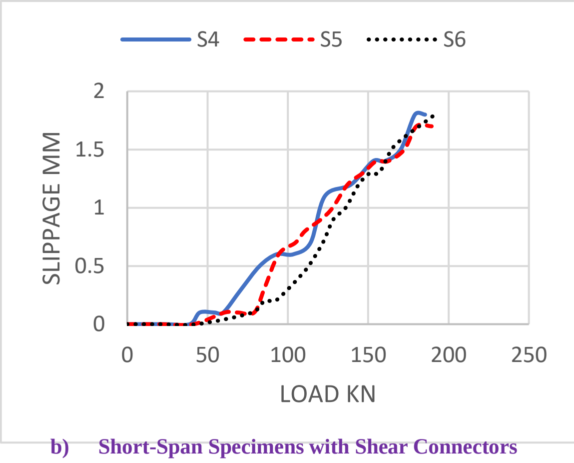
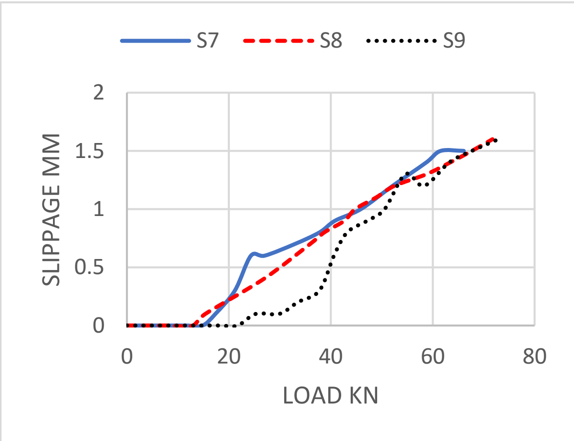
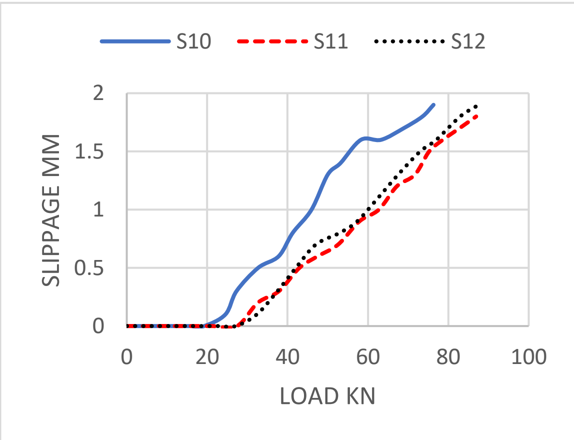


b) Short-Span Specimens with Shear Connectors



c) Long-Span Specimens without Shear Connectors



d) Long-Span Specimens with Shear Connectors

Figure 15 Slippage of Slab

IV. Evaluation of m-k Values and Shear Bond Capacity

Experimental research was conducted, and its main objective was to determine the shear bond capacity of the composite deck slab using the m-k method, which is explained in detail in Euro code 4 [7]. This code was used to evaluate m-k method values to determine the value of the bonding capacity of the surface of a composite deck slab. Based on test results, where m represents the value of mechanical interlock between concrete and steel sheet and k represents the experimental value of friction between concrete and steel sheet. Table (5) shows the details for the calculated values of m and k by drawing the m-k curve.

Accordingly, the formula for the equation that will be utilized is as follows:

$$\frac{\mathrm{Vt}}{\mathrm{bdp}} = \mathrm{m}\left(\frac{\mathrm{Ap}}{\mathrm{b\,Ls}}\right) + \mathrm{k} \qquad \text{Eq. (1)}$$

Where:

Vt = the maximum experimental shear force.

b = the width of the slab.

Ap = the cross-section area of the profiled sheet.

Ls = shear span of composite slab.

dp = effective depth of the slab from the top surface to the center of the steel sheet.

The results of the m-k values were obtained, and from them, the shear bond capacity between the lightweight concrete and steel sheet (τ v) is calculated according to Eurocode-4 [7] by equation (2). The shear bond capacity of all specimens is listed in Table (5).

$$\tau v = (m \times Ap) / (b \times Ls) + k \qquad \text{Eq. (2)}$$

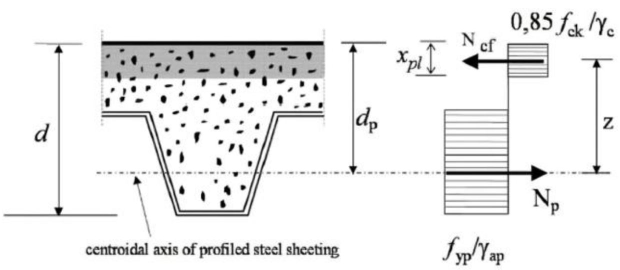
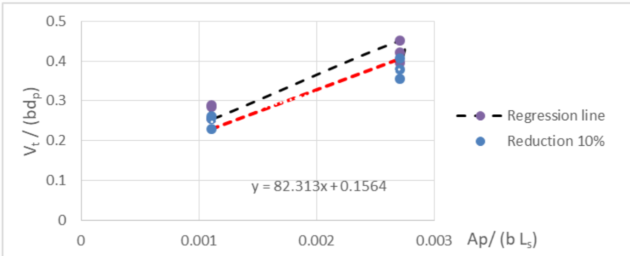


Figure 17 Plastic Stress of Composite Slab



a) Specimens Without Shear Connectors

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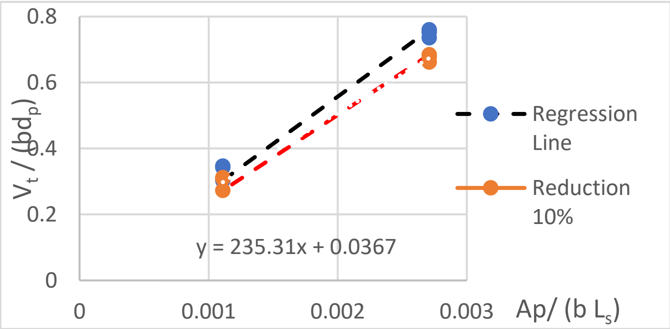

b) Specimens With Shear Connectors

Figure 18 m-k Curve

Table 5 m-k Values and Shear Bond Capacity

Speci-mens	V_t KN	L_s mm	M KN.m	Ap/(b Ls)	Vt/(b d_p)	m	k	τ_v N/m m^2
S1	52.95	330	17.47	0.00271	0.420	82.313	0.1564	0.379
S2	49.60		16.36	0.00271	0.394			
S3	56.85		18.76	0.00271	0.451			
S4	92.65		30.57	0.00271	0.736	235.31	0.0367	0.674
S5	94.70		31.25	0.00271	0.752			
S6	95.75		31.59	0.00271	0.760			
S7	32.00	805	25.76	0.00111	0.254	82.313	0.1564	0.247
S8	35.65		28.70	0.00111	0.283			
S9	36.45		29.34	0.00111	0.289			
S10	38.16		30.71	0.00111	0.303	235.31	0.0367	0.297
S11	43.20		34.78	0.00111	0.343			
S12	43.78		35.24	0.00111	0.347			

From Table 5, it appears that the tolerance of specimens with short spans is higher than that of specimens with long spans, by about 20% to 90%.

From Figure 17 and Table 5, it is clear that the specimens that contain shear connectors have proven to be better than the specimens that do not contain shear connectors in carrying a higher load. The shear bond (τ v) strength between the lightweight concrete and the steel sheet is higher in specimens containing shear connectors than in the other specimens. The shear bond increased by about 20% to 78% between the specimens that contain shear connectors and those that do not contain shear connectors for short and long spans respectively.

V. Analytical Studies

A. Using British Standard

As per BS-5950-Part-IV-1994 [15], the flexural capacity of the full connection should be treated as the upper limit for the capacity of the composite deck slab. The flexural capacity of the positive parts is calculated by imposing the stress on the rectangular parts of both concrete and steel sheets. The design strength of concrete must be taken as 0.45 Fcu for the concrete and the same as profile steel sheeting. "z" is the lever arm, which must not exceed "0.95 dp". In addition, the depth of concrete must not exceed "0.45 dp". It is found that the equations used in this case are the following:

$$T = 0.95\ Ap\ Pyp \qquad \text{Eq. (3)}$$

$$C = b * X * 0.45 * fcu \qquad \text{Eq. (4)}$$

$$MRd = T * (dp - 0.5\ x) \qquad \text{Eq. (5)}$$

Where:

Ap = cross-sectional area of profile sheeting in mm2

X = depth of neutral axis under full interaction in mm.

Pyp= design strength of profile steel sheet in MPa.

When the capacity of the controlled composite deck slab is the shear bond between concrete and steel sheet, it should be expressed in terms of vertical shear capacity at support. In general, the capacity of the shear bond can be calculated using the following equation:

$$Vs = \frac{Bs\ ds}{1.25}\left(\frac{mr\ Ap}{Bs\ Lv} + kr\sqrt{fcu}\right) \qquad \text{Eq. (6)}$$

Where:

Bs = width of composite deck in mm.

Lv = shear span in mm.

mr, kr are empirical parameters that should be obtained from parametric tests for the particular profile steel sheet, as per British Standard BS-5950-PART-IV-1994.

B. Using American Standard

As per ANSI-SDI [16], the pre-qualified section method shall be used to calculate the strength of the composite steel deck when there are no vertical anchors located on the beam flange supporting the steel deck. Classification of composite slabs subjected to surface curvature failure as over-reinforced under-slabs based on the depth of compression ratio (c/d). Slabs with a ratio (c/d) less than the equilibrium ratio (c/d) are considered insufficiently reinforced. While plates with a ratio (c/d) higher or equal to the equilibrium ratio (c/d) are considered to be overly reinforced. The compression depth ratio is calculated as follows:

$$\left(\frac{c}{d}\right) = \frac{Aş\ Fy}{F'c\ db\ \beta} \qquad \text{Eq. (7)}$$

The depth-to-pressure ratio is calculated in equilibrium states as follows:

$$\left(\frac{c}{d}\right)^{b} = \frac{0.003(h-d)}{\left(\frac{Fy}{Es}+0.003\right)d} \qquad \text{Eq. (8)}$$

Where:

As = area of steel deck in (mm2/m) of slab width.

b= unit width of the compression face of the composite slab (1000 mm).

c= distance from extreme compression fiber to composite deck slab.

d= distance from the extreme compression fiber to the centroid of the steel deck in mm.

h= nominal out-to-out depth of the slab, in mm.

β= 0.85

F`c = compressive strength of concrete

$$Mru = \phi s\ My \qquad \text{Eq. (9)}$$

$$My = Fy\ Icr / (h-ycc) \qquad \text{Eq. (10)}$$

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Where:
$\phi s = 0.85$
Fy = Yield stress of steel deck, (MPa)
Icr = Cracked section moment of inertia (mm4)
h = slab depth in mm.
ycc = distance from the top of the slab to the neutral axis of a cracked section in mm.
My =Yield Moment for the composite deck slab.

C. Using Euro Standard

As per Euro code 4 [7], the following assumptions are adopted:

- Full interaction between concrete, reinforcement bars, and steel sheet.
- The effective area of structural steel for design is emphasized to yield strength from either tension or compression.
- The effective areas of longitudinal reinforcement in cases of tension or compression are designed for the strength of yield fsd in tension or compression. Alternatively, reinforcement stress in the concrete slab can be neglected.
- The effective area of concrete withstands a compressive strength of 0.85 fcd.

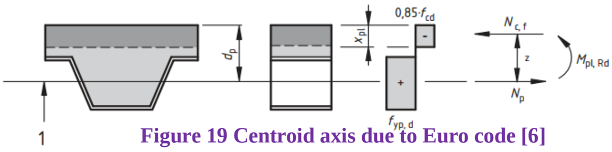

Figure 19 Centroid axis due to Euro code [6]

z and Mpr can be calculated according to the following equations:

z = h – 0.5 hc – ep + (ep – e) * Ncf / (Ape * fyp,d) Eq. (11)

Mpr = 1.25 Mpa (1- (Ncf / (Ape * fyp,d)) < Mpa Eq. (12)

When using the m-k method, which is based on the experimental method from six full-scale tests with varying shear spans. By the following equation:

$$V_{l,Rd} = \frac{b\,dp}{\gamma vs}\left(\frac{m\,Ap}{b\,Ls} + k\right) \qquad \text{Eq. (13)}$$

Where:
b, and dp are in mm.
Ap = nominal cross-sectional area of sheeting in mm2.
Ls = shear span in mm
γvs = Partial safety factor. The recommended value is 1.25.
m, and k are empirical factors

D. Results : international standards

The analytical study of the composite deck slab depends on the flexural capacity of all the composite slabs and their ability to bear the loads on each support. The supports are based on being a simple slab with one of the supports hinged and the second roller support. To allow for a simple comparison with other international codes and the slab that was made in the laboratory. The following results represented in Table 6 are the results of international standards for the bending capacity of slabs, with all sample requirements in terms of type of installation, slab thickness, and sheet type:

Table 6 Flexural Capacities of International Standards

International Code	Flexural Capacity (KN.m)	
	Short Span	Long Span
British Standard	22.9	27.07
American Standard	18.9	22.37
Euro Standard	23.5	29.70
Light-weight Deck Slab	24.3	30.75

Experimental results indicated that there is a convergence between the flexural components in laboratory slabs compared to analytical and confirmation using international codes. After comparing the samples, the average ratios were taken and compared to the international codes, and it was proven that the results were close to those codes. In the code, the shear in the samples is calculated without end anchorage. This is confirmed with international codes to set limits within which the results fall. This is accomplished to ensure the safety of the utilized samples and that they can withstand work in all climates and parts of the world. Also to ensure that it is not limited only to a specific country or place but allows it to work in all parts of the world, and therefore the validity of the results has been proven.

The research looks at two types of specimen fixation, the first without shear connections and the second in the presence of shear connections. But codes do not look at the method of fixation, and therefore, when comparing the results of the first method of fixation with the results of international codes, we found that the average of specimens that do not contain shear connectors and have short spans gave lower results with a percentage ranging from 20– 30%. Short-span specimens with shear connectors gave greater results with a percentage ranging from 25-35%. Specimens with long spans, starting with specimens that do not contain shear connectors, gave lower results by 5-10%, and specimens with shear connectors gave greater results by 20–30%.

VI. CONCLUSIONS

This study highlights the impact of shear connectors on lightweight composite slabs through the evaluation of 12 experimental specimens. These specimens were tested to examine the differences between slabs with and without shear connectors using lightweight concrete. The following key findings were drawn:

- Lightweight Concrete Characteristics: Lightweight concrete, particularly when pumice stone is used, achieves a compressive strength exceeding 400 kg/cm² after 28 days, making it a reliable alternative to regular concrete despite its reduced weight.
- Sliding Movement: Lightweight composite slabs with shear connectors exhibited 20-40% less sliding movement between the concrete and steel sheets compared to slabs without shear connectors.

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- Behavior of Lightweight Composite Slabs: Slabs with shear connectors demonstrated superior sliding resistance and ductility compared to those without shear connectors.
- Shear Bond Capacity: Using the m-k method, the shear bond capacity of slabs with shear connectors was found to be 20-78% higher than that of slabs without shear connectors.
- Span Impact: Short-span lightweight composite slabs showed flexural strength results that were 20-90% higher than those of long-span specimens.
- Code Compliance: Experimental results were consistent with analytical predictions based on various international codes, confirming their reliability.

These findings underscore the significant benefits of using shear connectors in lightweight composite slabs and provide insights into optimizing their design and application.

Conflicts of Interest: The authors declare no conflict of interest.

REFERENCES

[1] Bashar S. Mohamed, "Structural behaviour and m-k value of composite slab utilizing concrete containing crumb rubber", Dec. 2009 posted in (construction and building materials)

[2] K.M.A Hossain, professor, S. Allam, Post-doctoral fellow, M.S. Anwar, Research assistant, K.M.Y. Julkarnine, Research assistant, "High-performance composite slabs with profiled steel deck and Engineered Cementitious Composite-Strength and shear bond Characteristic", Aug. 2016 posted in (Construction and Building Materials)

[3] S. P. Siddh, Y. D. Patil, H. S. Patil, " Experimental studies on behavior of composite slab with profiled steel sheeting", April 2017 posted in (International Conference on Recent Trends in Engineering and Material Sciences)

[4] Hector Cifuentes, Fernando Medina, " Experimental study on shear bond behavior of composite slabs according to Eurocode 4", Dec. 2012 posted in (Journal of Constructional Steel Research)

[5] V. Marimuthu, S. Seetharaman, S. Arul Jayachandran, A. Chellappan, T.K. Bandyopadhyay, D. Dutta, " Experimental studies on composite deck slabs to determine the shear-bond characteristic (m-k) values of the embossed profile sheet", July 2006 posted in (Journal of Constructional Steel Research)

[6] Namdeo Adkuji Hedaoo, Laxmikant Madanmanohar Gupta, and Girish Narayanrao Ronghe, " Design of composite slabs with profiled steel decking: a comparison between experimental and analytical studies" Mar. 2012 posted in (International of Advanced Structural Engineering)

[7] Eurocode-4: Design of composite steel and concrete structures (1994-1-1:2004)

[8] Héctor Cifuentes, Fernando Medina, " Experimental study on shear bond behavior of composite slabs according to Eurocode 4", Dec. 2012 posted in (Journal of Constructional Steel Research)

[9] Thomas N. Salonikios, Anastasios G. Sextos, and Andreas J. Kappos, " Test on composite slabs for the evaluation of Eurocode 4 provisions for m-k factors and associated design issues " Oct. 2012 posted in (Institute of Engineering Seismology and Earthquake Engineering)

[10] Saravanan, M., Marimuthu, V., Prabha, P. Arul Jayachandran, S. and Datta, D., " Experimental investigations on composite slabs to evaluate longitudinal shear strength", Sep. 2012 posted in (CSIR- Structural Engineering Research Center)

[11] S. P. Siddh*, Y. D. Patil, H. S. Patil, " Shear bond failure in composite slabs a detailed experimental Study", Apr. 2011 posted in (Steel and Composite Structures)

[12] Sayan Sirimontree, Chanachai Thongchom, Suraparb Keawsawasvong, Peem Nuaklong, Pitcha Jongvivatsakul, Warayut Dokduea, Linh Van Hong Bui and Ehsan Noroozinejad Farsangi, "Experimental Study on the behavior of steel-concrete composite decks with different shear span to depth Ratios'', Dec 2021 posted in (Buildings Journals)

[13] Hanan H. Eltobgy, Kareem M. M. Abdelkareem, Mourad. M. Bakhoum, " Experimental study on shear bond behavior of composite deck slab Equipped with shear connectors", May. 2021 posted in (International Journal Of Scientific & Technology Research)

[14] Karthika R.B., Vidyapriya. V, Nandhini Sri K.V, Merlin Grace Beaula K, Harini R, Mithra Sriram, "Experimental Study on Lightweight Concrete Using Pumice Aggregate", September 2020, posted in (Materials Today Proceedings)

[15] BS EN 1994-1-1, Design of Composite Steel and Concrete Structures-Part 1-1 General Rules and Rules for Buildings, British Standards Institution, 2004.

[16] American National Standard Institute / Steel deck Institute, C-2011