Application of Composite Slab With Galvanized Steel Deck in Reinforced Concrete Frame

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ABSTRACT

Composite slab which consist of galvanized steel sheet with in-situ concrete is widely used in steel framed structure due to its advantages in terms of overall weight of the structure, efficiency, practicality as it is used as a permanent form work and as positive reinforcement after the hardening of the concrete. Furthermore, it is non-propped in most of the cases. This research was aimed at investigating the possibility of using the composite slab with galvanized steel deck in reinforced concrete (RC) frames. Investigation of the efficiency and the applicability of the system included the evaluation of the composite slab with RC beam by using three different static test. Flexural capacity of the new system was investıgated through the four-point static test. These tests were used to assess the behavior of the slab which was carried by the RC beam under gravity load and the behavior was compared with the traditional concrete solid slab. Shear bond test has been done to evaluate the locally available material by m-k value method. Push-of test has been done on a series of specimens to find out the amount of slip between the beam and the slabs. As a result, it was found that the composite slab can be applied in a RC frame with a special practical consideration. Moreover, the overall weight of the RC framed structure can be reduced by using this type of slab instead of solid concrete one-way, two-way slabs, joist and flat slabs and this approach may also speed up the construction process.

Keywords: Composite Slab, Static Test, Shear Bond, m-k Value, Slip Capacity, Push-of Test, Steel Sheet, Composite Slab in Reinforced Concrete Frame.

ÖZ

Galvanize edilmiş çelik saç ve beton kullanılarak oluşturulmuş kompozit döşeme kalıcı bir döşeme kalıbı oluşturmada ve pozitif moment bölgesi donatısı olarak kullanılmada sağladığı verim ve yeterliliğiyle, bina toplam ağırlığının azaltılmasında yarattığı avantajlarıyla çelik çerçeve inşaatlarda yaygın olarak kullanılmaktadır. Ayrıca çoğu zaman desteksiz olarak kullanılmaktadır. Bu araştırma, galvanize edilmiş çelik saç ve beton kullanılarak oluşturulmuş kompozit döşemenin betonarme (BA) çerçevelerde kullanımını incelemek için yapılmıştır. Sistemin verimliliğinin ve uygulanabilirliğinin araştırılması, üç farklı statik test kullanılarak kompozit döşemenin BA kiriş ile birlikte davranışının değerlendirilmesini içeriyordu. Dört nokta statik testi kullanılarak yeni sistemin eğilme kapasitesi araştırıldı. Bu testler, betonarme kirişi tarafından düşey yükü altında taşınan döşemenin davranışını değerlendirmek için kullanılmış ve davranış geleneksel beton döşemeyle karşılaştırılmıştır. Yerel olarak mevcut malzemeyi m-k değeri yöntemi ile değerlendirmek için kayma bağ testi yapılmıştır. Kiriş ve döşeme arasındaki kayma miktarını bulmak için bir dizi örnek üzerinde push-test yapılmıştır. Sonuç olarak, kompozit döşemenin BA çerçevelerde pratik yaklaşımlar değerlendirilerek uygulanabileceği tespit edilmiştir. Ayrıca, geleneksel tek ve iki yönlü, kirişli ve düz beton döşemeler yerine bu tip kompozit döşeme kullanılarak BA çerçeve yapıların toplam ağırlığı azaltılabilir ve yapım süreci de hızlandırılabilir.

Anahtar kelimeler: Kompozit Döşeme, Statik Test, Kayma Bağı, m-k Değeri, Kayma Kapasitesi, İtme Testi, Çelik Saç, Betonarme Çerçevede Kompozit Döşeme.

DEDICATION

For my father, my god-father, and my friends for all the people who I lost during the journey of my life RIP.

For my family whom I missed the most

For my future wife who is waiting for me to visit her city

For my second family in North-Cyprus

To my homeland where I cannot go

I would like to attend this achievement with all of you but it is up to fate what I can say now tomorrow will be better.

ACKNOWLEDGMENT

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A_p	The Effective Cross-section of the Steel Sheet.
b	The Width of the Specimen.
d_p	The Depth of the Specimen from the Neutral Axis of the Steel Sheet.
f_c	The Concrete Cylinder Strength.
G	Dead Load.
k	Parameter That Represent the Shear Bond Due to Friction between Concrete and Steel Sheet.
ks	Rotational Stiffness Coefficient.
m	Parameter That Represent the Shear Bond Due to Mechanical Interlock Between Concrete and the Steel Sheet.
P_u	The Applied Failure Load.
Q	Live Load.
τ_{u,R_d}	Shear Bond Capacity.
V_t	The Reaction Load Which Equal to W_t Over 2 As The Specimens Show a Ductile Behavior.
W_{DL}	The Weight of the Specimen Including the Steel Sheet Weight and the Spreader Beams Weight.
W_t	The Sum of W_{DL} and P_u.
$W_{0.1}$	The Load Which Caused 0.1 mm End-Slip Plus the Self-weight of The Specimen.
CS-SC	Composite Slab Specimen with Shear Connector.
ECC	Green Cost-effective Concrete.
EMU	Eastern Mediterranean University.

FRC	Fiber Reinforced Concrete.
HSC	High Strength Concrete.
LS	Long Span.
L_s	The Shear Span Length.
LTB	Lateral Torsional Buckling.
LVDT	Linear Variable Displacement Transducer.
LWC	Light Weight Concrete.
RC	Reinforced Concrete.
SC	Slip Capacity Specimen Without Slab Reinforcement and Connector.
SC-Con	Slip Capacity Specimen with Connector.
SCC	Self-compacted Concrete.
SC-FR	Slip Capacity Specimen with Full Reinforcement.
SC-SR	Slip Capacity Specimen with Slab Reinforcement Only.
SS	Solid Slab.
SS	Short Span.

Chapter 1

INTRODUCTION

1.1 Introduction

Folded iron is the ancestor of today's profiled sheet which was licensed in 1829. Forming iron into thin sheets with trapezoidal shapes rise and fall to provide stiffness was initially the scheme of Henry Robinson Palmer who was a laborer at the London Dock and Harbour Company. The definition of composite slab formed by using galvanized steel sheeting as a permanent shuttering and tension reinforcement to a concrete slab has now become a usual method of construction for composite floors in steel framed buildings.

Composite slab construction has been common over the last three decades and has mostly accounted for the dominance of steel frames in multi-story building. Composite slab construction has become widely used because it integrates structural efficiency with speed of construction to offer an economic solution for a wide range of building. Nowadays, the definition of composite slab, which consists of galvanized steel deck with in-situ concrete, is applicable when the deck guarantees an acceptable shear bond with the concrete. In this case the steel deck is not only a permanent form work which is responsible to carry the construction loads during the implementation, including the wet concrete during casting process, but it also acts compositely with the concrete slab and tension reinforcement, if shear bond is guaranteed. Fast track construction is associated with the beam and slab in steel structures due to the ease of application with lighter building. This makes the composite slab one of the most competitive choice of slabs in steel framed buildings. As the adhesion between concrete and steel sheet is usually insufficient to ensure composite action after concrete hardened then a number of alternatives has been developed to increase the adhesion. For instance, trapezoidal profile shape, mechanical anchorage, embossments, end anchorage.

1.2 Advantages and Disadvantages of Using Composite Slab

The advantages of using composite slab can be summarized as follows

- Faster construction: The light weight of the sheets minimizes the transportation time and the time which the crane spends to transfer the material. Moreover, the implementation of the composite slab is quite simple when compared to other slabs since it often only needs shrinkage and temperature reinforcement after placing the sheets on beams.
- Lighter construction: With a thin sheet and approximately 25% less concrete the composite slab can gain the same stiffness as the other types of reinforced concrete slabs. Hence the members of the structural frame are smaller in cross section and lighter too. As a result, loads on foundation becomes less leading to smaller size foundation since the slab weight dominates the overall weight of the building.
- Cheaper construction: The use of composite slab together with steel beam lead to beam becoming composite and hence composite action helps to restrain the compression flange of the beam along its length against lateral torsional buckling (LTB). LTB can be defined as one of the main problems that steel beams can face in steel framed buildings. The composite beam is usually

requiring lighter steel beam section than the non-composite steel beam. Therefore, lighter beams result in lighter columns and less material use.

Sustainable construction: Steel has the ability to be fully recycled and hence the steel sheet will be re-used after the demolition of the building. This will lead to less material usage which results in less material waste.

The disadvantage can be summarized as:

- The shear bond which develops between the steel sheet and the concrete is an important phenomenon that requires a special care during the design of composite slab. To handle this matter raised parts need to be formed on the sheet surface to help develop the shear bond. This process is additional work and hence increases the cost of forming the trapezoidal deck.
- The slip between the composite slab and the steel beam makes the slab diaphragm flexible which is not preferable in case of seismic design.

Since no past research or usage of composite slab in RC frame has been found during the literature review then there is a need for thorough investigation of this topic.

1.3 Aim of Study

This study is aimed at using composite slab with galvanized trapezoidal steel sheet composite with in-situ reinforced concrete (RC) beam in RC frame. The experimental work was carried out to provide an insight into the behavior of RC beam with the composite slab. The thesis provides recommendations on application of composite slab with galvanized steel deck within RC frame under gravity loads. The results of the experiments are expected to give enough information on the behavior of such arrangement and the possible benefits of using composite slab with galvanized steel deck within RC frame.

1.4 Scope of Study

A total of twenty-two specimens were designed and tested in order to investigate three main aspects.

- Flexural capacity of the new system by using the four-point static test with three composite slab specimens and one traditional concrete solid slab as control specimen carried by reinforced concrete beam.
- Shear bond capacity by using m-k value test which means measuring the shear bond between the steel sheet and the in-situ concrete in-terms of chemical and physical bond.
- Slip capacity of the system by using a push-of test to evaluate if any slip occurs between the RC beam and the slabs with four different test cases.

1.5 Outline of Study

Chapter 1 gives a brief introduction to the subject matter. It introduces the aim and scope of the study and the content of thesis in each chapter.

Chapter 2 summarizes the literature survey on composite slab in three different aspects; the behavior of the slab under static test carried by composite beam, the shear bond between the steel sheet and the topped concrete by using m-k value method, and the slip capacity between the composite slab and the composite beam.

Chapter 3 provides the details of the test program for three different aspects detailed in Chapter 2 where RC beam was used instead of composite steel beam. The experiments carried out in this thesis are

a) the static test that has been done by using three different composite slab samples carried by RC beam and are compared to a control sample which is known as a traditional solid concrete slab carried by RC beam.
b) the m-k value test that has been done on six different specimens three with long span and three with short span.
c) the slip capacity tests were carried out using 12 different specimens with four different cases to investigate the main components which play the main role in bonding the composite slabs to the RC beam.

Chapter 4 deliver the results and discussions of the experimental test.

Chapter 5 compares the composite slab with traditional one-way and two-way concrete solid slabs by using each slab type with the same structural frame model by using ETABS 2016 general structural design software. Comparison was done by using three different parameters weight of the structure, amount of material used, and time taken for construction.

Chapter 6 is the overall conclusion of this study together with recommendations for future work.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

Type of slab in a building is very important due to its contribution to self-weight, diaphragm action and also its effect on the overall behavior of the structural system. Among the slabs commonly used for reinforced concrete (RC) buildings are solid one-way or two-way slabs, joist floors, waffle slabs and flat slabs with each one having different advantages and disadvantages. On the other hand, slabs composite with galvinized steel trapezoidal deck and pre-cast slabs are the common floor systems for steel framed buildings. While trying to decrease the weight of the RC buildings and enhance their overall behavior with speed in the construction process the composite slab which consists of a galvanized steel trapezoidal deck and in-situ concrete could be a suitable alternative to the in-situ RC slab alternative. So far there is no evidence in literature showing that this kind of composite slab with galvanized deck are used in RC buildings.

Hence, there is need to understand such slabs individual behavior and also behavior as part of an RC frame. To do that one needs to understand how such slabs behave within a steel framed building and hence try to understand how it would behave as part of a steel framed building. There is adequate number of research results on experiments carried out for slabs composite with steel deck in steel formed buildings. It is important to understand the physical and chemical interactions between the concrete and the steel sheet by means of m-k value tests or partial shear connection tests. This depends on particular circumstances as partial shear connection method can be applied on ductile longitudinal shear behavior only, on the other hand, m-k value method can be applied on both ductile and brittle longitudinal shear behavior. In addition, the influence of the composite slab on RC beam in the shear transfer zone can be obtained through a push of test which represent the slip capacity of the system. Moreover, the overall behavior of the structure is studied via the four points static load test. However, there is lack of data on investigation of RC frame with slab composite with steel deck in literature. Therefore, the litrerature survey will cover past study on steel framed buildings with slabs composite with steel deck. Then the approaches developed for understanding the behaviour of such systems will be considered to be applied as it is or as modified to the slabs composite with steel sheet in RC frames.

2.2 Static Test

Nie and Wang [1] developed a series of static test on a composite slab with profiled steel sheeting carried by a composite beam where a welded shear stud was used. They claimed that including the slip impact has remarkably enhanced the prediction of the deflection. The slip effect developed an extra flexural moment which caused a reduction in the elastic flexural capacity. In addition, the researchers discovered that the spacing of studs influences the total shear capacity. Furthermore, Nie and Cai [2] suggested the same thing while they were working on a simply supported and a continuous composite beam carrying a composite slab. Their further observation of the failure mode indicated that composite beam failure mode relies on the shear connectivity degree. Accordingly, when rotational stiffness coefficient, k_s (EN4-1-1 clause 6-4-2-6) is more than 0.5 concrete full strength can be achieved with an efficient ductility of the connector and when k_s is less than 0.5 the capacity of the beam can be governed by the failure of the connector. Xing, et. al [3] have compared the structural behavior of composite beam with normal concrete and elastic concrete (concrete with an amount of recycled rubber to enhance the flexural properties of concrete) and they claimed that the static mode of failure of the elastic concrete-steel composite beam is almost identical to a usual composite beam with a more tiny crack in the pure bending zone and a better distribution of load. With the segment of composite beam unaltered, controlled factors (steel beam section, width of slab, amount of rubber, diameter of stud, number of stud, and degree of shear connection) had less impact on the ultimate bearing capacity and elastic stiffness of the slab yet more impact on total deformation. With the utilization of elastic concrete elastic stiffness can be residual at a high level during the time that the deformability and ductility are enhanced clearly in the meantime. Meanwhile, the addition of rubber particles in the mix design and the increase in the connector diameter led to a weakness in the composite action. With the same context, Ataei, et. al [4] investigated a series of composite beams having a pre-cast geo-polymer concrete slab with a deconstructable bolted connectors and they found out that the use of these types of connectors have almost the same stiffness both in partial shear connection and full shear connection. Although embedded single connector had more ultimate load capacity than the post-installed connector but it is less ductile. On the other hand this category of connectors has an advantage that they are deconstructable and all the elements can be reused.

2.3 Shear Bond Capacity

Cifuentes and Medina [5] carried out a series of shear bond behavior tests on composite slabs by using m-k value method and partial shear connection method in accordance with Eurocode 4. EN 1994-1-1 annex B3 requires the first specimen to be tested in about an hour under static load, then second and third specimens to be subjected to 5000 cyclic load between 0.2W and 0.6W, before being crushed under static load. W is the the failure load of the first specimen plus the weight of the specimen. This process should take a minimum of three hours During this time a crack inducer should be placed at the mid-span to neglect the concrete tensile strength, end-slip and mid-span deflection should be measured, the weight of the slab with the weight of the spreader beams should be added to the applied load. The span of the slab should be devided into four equal segments and the line load should be applied at span/4 from right and left end of the slab. Span/4 is known as the shear span under four point loads. They reported that placing a crack inducer in the slab does not affect the result despite the underestimation of the longitudinal shear as they found that the shear-span is self-defined by the apparent cracks. Moreover, they claimed that the gauge of the sheet is important with regards to longitudinal shear mainly for long span specimen. This was due to the fact that the use of ultimate shear value acquired by a thinner sheet was led to an underestimation of the ultimate shear capacity of the thicker sheet and utilization of an m-k value test will result in more accurate shear capacity. They also concluded that the load carrying capacity of the composite slab has not been affected by the previously applied cyclic loads required by Eurocode 4. Besides, the mid-span deflection and end slip values were higher for the specimens with cyclic loads.

With the same argument Hossain, et. al [6] investigated a series of composite slabs using green cost-effective concrete (ECC) and normal self-compacted concrete (SCC) and they suggested that longer shear span evolved with more stress/strain in the sheet in comparison with shorter shear span and SCC steel strain was less than ECC samples. Thus, in general, the ECC had developed a better shear bond with the steel sheet than SCC case while increasing the shear span lead to decrease in the failure load. Also the utilization of shear stud in composite slab resulted with a higher load carrying capacity and reduced deflection.

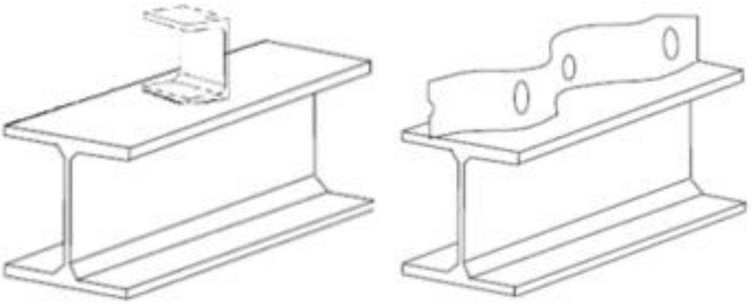
With the same context Lakshmikandhan, et. al [7] have tried to enhance the shear bond capacity of the composite slab by using different types of interfaced mechanical connectors (using two different methods of inserting rebar through the steel sheet and using wire mesh as temperature and shrinkage reinforcement instead of rebar) and they found out that the introduction of steel shear connectors improved the brittle behavior of some of the composite slab types and make them more ductile. Furthermore, all three interfaced mechanical connectors initiate full shear interaction without any apparent slip. When steel rods were placed in the web of the deck this led to restraining the deck and improved its strength and stiffness. Briefly, the outcome was that the shear connectors could improve the load carrying capacity of slab by about 110% when compared with the same thickness composite slab without shear connectors. However, the results of using wire mesh instead of rebar for shrinkage and temperature appears to be more competitive.

Whats more Marimuthu, et. al [8] has tested a series of embossed composite slabs in order to examine the effect of shear span on the shear bond between concrete and the steel sheet. They claimed that the overall behavior of an embossed composite slab was mainly affected by the shear span. In the case of short shear span the ultimate strength of the slab was effected by the failure of the shear bond. In the case of a long shear span (the segment of the slab where the shear value is maximum), up to 1.25 m, the ultimate behavior of the slab dominated by flexural failure. Furthermore, the slip in the specimen was existed in the early stage of the loads which it can be enhanced by modifying the thickness of the embossment, the width of the embossment and the thickness of the concrete portion above the steel sheet. They reported that the cyclic load suggested by Eurocode 4 (EN 1994-1-1 2004) does not have any influence on the load carrying capacity of the slab. Eventually they found out that the difference between the longitudinal shear which is calculated by m-k value method and by partial shear connection method is about 26%.

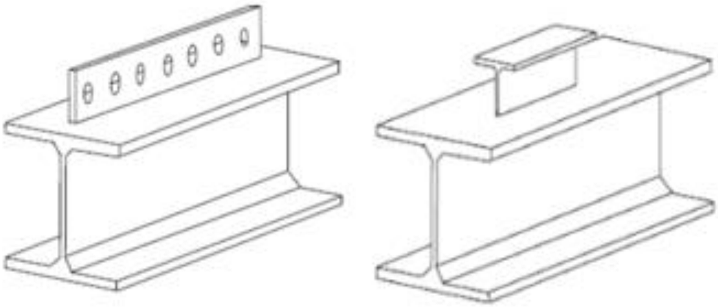
2.4 Slip Capacity

Although all the previously mentioned information are important the main challenge in composite slab is the slip capacity, which represents the composite action between the composite beam and the slab. This thesis aims to invistegate a reinforced concrete beam carrying a composite slab with galvanized trapezoidal steel sheet. Hence, it is important to find what types of shear connector can be used and what is available in the literature regarding this matter. In this context, Shariati, et. al [9] published a state of the art on different types of shear connectors. Figure 2.1 displays most of the shear connectors which were rused in their study. They concluded that with the aim of removing the problems (practical considerations, such as, the quality of the weld on the site) related with standard shear studs, the perfobond shear connector can be used. In order to look at the conduct of composite members utilising the perfobond connectors, a coordinated experimental and analytical research was developed. T-perfobond connectors were presented.For the same longitudinal plate geometries, the capacity and stiffness of this kind of connector are usually higher than that of the perfobond connectors . In addition, the generation of these connectors with customary laminated I or H segments minimize workmanship and material use,thus providing advantages . Moreover due to a quick drop in the ultimate load capacity after reaching their peak it draws unwanted performance when using oscillating perfobond strip connectors in normal strength and normal weight concrete despite the fact that their load capacity is larger than headed stud. Besides, the goal of using curved form of stud was to increase the friction between the connector and the surrounded concrete yet it was observed that the use of suchstud resulted in difficulty in the welding process which meansspecial attention is required. Whats more, the T-connector behaviour is preferably measured with the stress on the front side of the T and is highly relevant to a small area. The total load carrying capacity is close to oscillating perfobond strip connector. Yet its ductility is larger especially when used with FRC (fiber reinforced concrete), LWC (light weight concrete), and HSC (high strength concrete) when there is a remarkable rise in the ductility and overall load capacity.

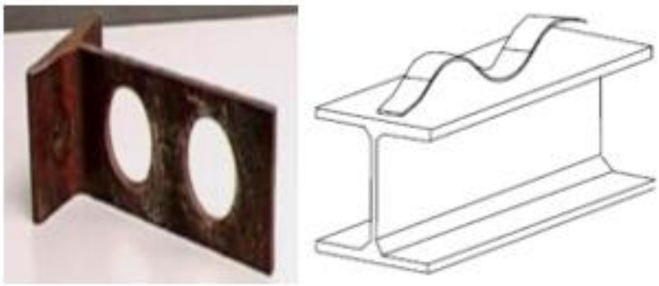
An and Cederwall [10] has reviewed two types of slip capacity tests where the test specimens were prepared by using welded stud with normal strength concrete and high strength concrete. They reported that the increase in the compressive strength of concrete from 30 to 80 MPa lead to approximately 34% increase in the overall shear load resistance of the connectors whilst the total slip was almost the same in both cases. On the other hand, the behavior of the welded stud with normal strength concrete was more ductile than the one with high strength concrete. Furthermore, the amount of reinforcement in normal strength concrete specimen has a minor effect on the total load while its effect is negligable for high strength concrete.



Channel connector Oscillating-perfobondstrip connector



Perfobond ribs connector |T shear connector



T-RIB connector Waveform-strip connector

Figure 2.1: Types of shear connectors.

An and Cederwall [10] has reviewed two types of slip capacity tests where the test specimens were prepared by using welded stud with normal strength concrete and high strength concrete. They reported that the increase in the compressive strength of concrete from 30 to 80 MPa lead to approximately 34% increase in the overall shear load resistance of the connectors whilst the total slip was almost the same in both cases. On the other hand, the behavior of the welded stud with normal strength concrete was more ductile than the one with high strength concrete. Furthermore, the amount of reinforcement in normal strength concrete specimen has a minor effect on the total load while its effect is negligable for high strength concrete.

Hirama, et. al [11] had reviewed 1002 push tests result with headed studs. Their review was concentrated on the type of slab, mode of failure and diameter of headed stud. They found out that the shear resistance in the slab with steel sheet is marginally less than that of a solid slab. This small difference could be due to the variation in the testing process. Thus they concluded that the shear capacity is almost the same in both types of slab. On the other hand the cross-type steel sheet resulted in diverse inclination from the solid slab. Hence, it was claimed that the concrete surrounding the shear stud plays a major role in defining the shear capacity in the slab with steel sheet. From the results it is clear that the cross-type slab (another name of trapezoidal shaped steel deck) with welded studs do not return back to the origin and the effect of stud diameter and strength is restricted. Few other results found in the literature on large diameter studs show that the total shear capacity of studs with the solid slab decrease when the stud diameter was increased. Jayas and Hosain [12] had also carried out experiments on slip capacity test on 18 specimens to investigate the effect of headed stud on the behaviour of composite beam. This composite beam was part of a composite slab which consist of trapezoidal steel deck and normal strength concrete ribs being parallel or perpendicular to the beam with center of attention being on the spacing of the studs and the rib geometry. They reported that the samples with parallel deck or solid slab exhibited a mode of failure which can be represented by the shear failure of the stud. The samples had wide rib profile with wide spacing between the studs. Moreover, concrete cone crushing mode of failure was observed in the specimens which had closely spaced studs with a solid slab or parallel placed profile. The results indicated a drop in the stud shear carrying capacity by 7 % in the solid slab and about 14 % in ribbed slab placed parallel to the beam. Han, et. al [13] had tested 18 push-of samples to examine the behavior of embedded stud with elastic concrete and different amount of rubber. They found out that failure of the stud shank was the major mode of failure with a ductile behavior as the elastic concrete exhibitted more local cracking resistance than normal concrete. Also, the load-slip relationship was categorized as ductile according to Eurocode 4 requirements (6 mm slip is required to define the failure as ductile failure). The deformation and ductility level of studs increased with the increase in the rubber content in the elastic concrete and the stiffness was decreased quickly when the rubber amount was around 15%. However, the optimum rubber content was found to be 10 % as the specimens show high capacity, greater deformation and larger ductility. Wang, et. al [14] had investigated a series of push-off tests on demountable headed stud connectors with ultra-high performance concrete since the embedded studs exhibit a brittle behavior with this type of concrete and their main parameters were the aspect ratio and connector diameter. They conclude that the cone crushing of concrete and the fracture of the stud were the two modes of failure observed. The mode of failure corresponding to the aspect ratio at concrete cone crushing took place when the aspect ratio was less than 1.5. For equal stud collar diameter, when the aspect ratio increased the ultimate shear strength of the connector also increased. The ductility of demountable connector found to be competitive when compared to a normally embedded stud but less than the requirements of Eurocode 4.

2.5 Summary of Literature Review and Aim of This Research

Briefly, literature review on composite slab connected to composite beam or a solid slab connected to a composite beam can be summarized as follows. Although the literature is full of data about steel beam being composite with solid or steel plated concrete slab with shear studs, there is a lack of information about reinforced concrete beam composite with concrete slab with steel deck which is the main concern of this research. Investigation in this line is expected to lead to standardized tests on composite slab with composite beam to find out its behavior under gravity loads. Hence, the first step is to investigate the behaviour of composite slab that consist of trapezoidal galvanized steel sheet and concrete connected on both sides of a reinforced concrete beam.

Chapter 3

METHODOLOGY

3.1 Introduction

A total of twenty-two specimens were tested in three different test set-up as follows:

- Static test was carried out to evaluate the behavior of the new system under flexural load. Then the behavior of new system was compared to the traditional concrete solid slab system to get an idea about the efficiency of the new system (four specimens).
- Shear bond tests were carried out by using m-k method to assess the applicability of the locally available material in designing such a composite slab (six specimens).
- Push-of tests were necessary to see if slip occurs between the composite slabs and the reinforced concrete beam for the new system. This test is routine when steel beam is connected to composite slab with steel deck (twelve specimens).

The dimensions and details for the specimens taken from an assumed residential building (building plan layout and floor heights are given in detail in chapter 5) with an imposed load of 3 kN/m² and finishing load of 1.2 kN/m².

3.2 Test Program

The test program consists of three different tests each of them will measure different aspect to meet the design and serviceability criteria. In order to do so a multiple number of each test has been carried out to avoid the residual error which can occurred in each sample. During the tests a 500 kN hydraulic jack with hand operated pump was used to apply the load and Linear Variable Displacement Transducers (LVDT) were used to measure the displacements at different locations. Data has been recorded by using data logger with an interval of 1 second. Ready mixed concrete was used for these tests with high volume of concrete whereas the rest of the specimens were concreted in the laboratory. For composite slab Almetsan ALDECK 70/915, with a deck depth of 60mm, thickness of 1 mm and an embossment distributed on the web of the sheet, was used. The dimensions of the galvanized steel deck are shown in Figure 3.1.

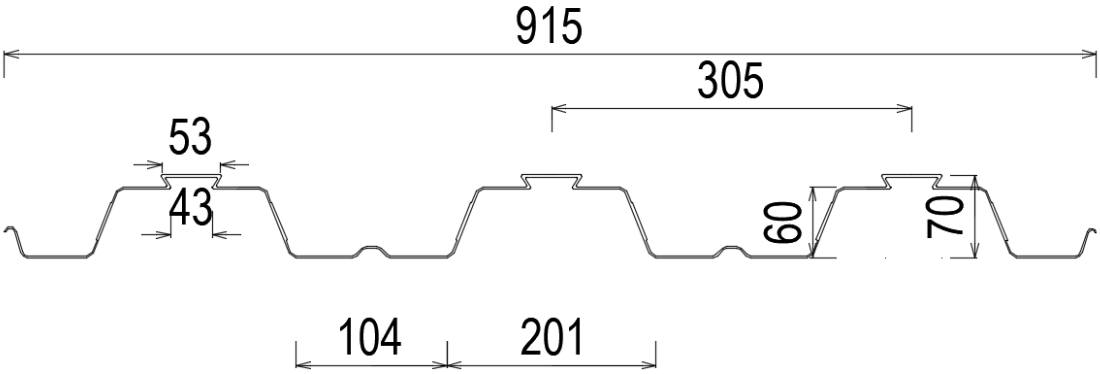


Figure 3.1: Dimensions and details of steel sheet.

The yield and tensile strength of the galvanized sheet and deformed bar S420 can be found in Tables 3.2 and 3.3, respectively, with the degree of elongation for each sample. Tensile tests were carried out at Mechanical Engineering Department laboratory in Eastern Mediterranean University (EMU).

Table 3.1: Yield and tensile strength of the galvanized steel sheet used for experimental work.

Sample	Area (mm²)	Yield load (KN)	Fracture load (KN)	Lo (mm)	Lf (mm)	Elongation (mm)	Yield stress (MPa)	Tensile stress (MPa)	Elongation %
1.0	18.7	6.0	7.1	80.0	104.4	24.4	320.1	378.8	30.4
2.0	18.2	6.2	7.1	80.0	100.4	20.4	339.9	389.3	25.5
3.0	18.5	6.4	7.1	80.0	102.1	22.1	345.8	383.7	27.6

Table 3.2: Yield and tensile strength of the S420 rebar used for experimental work.

Sample	Area (mm²)	Yield load (KN)	Fracture load (KN)	Lo (mm)	Lf (mm)	Elongation (mm)	Yield stress (MPa)	Tensile stress (MPa)	Elongation %
1.0	50.2	26.1	30.7	80.0	92.0	12.0	519.5	611.1	15.0
2.0	50.2	22.0	26.7	80.0	94.0	14.0	437.9	531.4	17.5
3.0	37.4	22.8	27.4	80.0	95.0	15.0	610.1	733.1	18.8

The details about each test, such as, material properties, preparation, test set-up and loading procedure, etc. are discussed in the following section.

3.2.1 Quasi Static Test

The test has been done by using a simply supported reinforced concrete (RC) beam carrying a continuous RC slab to investigate the behavior of both of them under four-point load (two loads applied on the slab and two reactions from the supports) primarily for flexural behavior. The overall length of the specimens was 3700 mm with a pure bending (pure bending is the distance between the two line loads) of 250 mm. 150 mm thickness was used for both solid slab and composite slab. Both slabs were carried by a 25/45 cm RC beam. The reinforcement in solid slab was Ø8/17 in the short direction and Ø8/25 in the long direction with Ø8/25 at the negative moment zone to make it similar to the composite slab, since mesh reinforcement were existed there. On the other hand, the composite slab had only a mesh reinforcement with Ø8/25 in both directions to prevent concrete shrinkage cracking. Finally, the RC beam has 3Ø12 rebar at top and bottom for flexure and Ø8/20cm, as shear reinforcement. Figure 3.2 shows the cross section of concrete solid slab (SS) and composite slab (CS-SC).

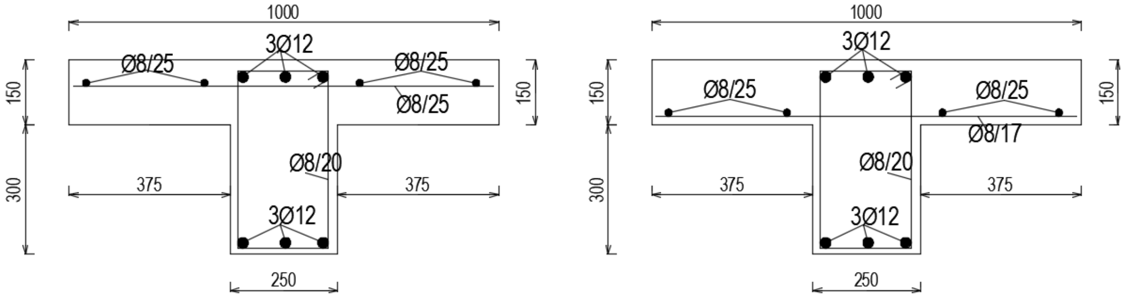


Figure 3.2: Cross-sectional details for RC beam with composite (left) and solid slab (right).

3.2.1.1 Material Properties and Sample Preparation of Quasi Static Test

Four different specimens have been prepared and tested where three of them with composite slab carried by RC beam and the fourth one was a concrete solid slab carried by RC beam as control specimen. After the formwork was prepared in the laboratory, the reinforcing bars were fixed according to design. The free ends of the slabs were temporarily supported to prevent any deflection during the casting. Then the concrete was cast in the EMU structures laboratory. Table 3.4 shows the concrete mix design and concrete main strength properties.

Ready mixed concrete was used for casting the specimens. 6 cube samples have been taken from the mixer two for 7-days compressive strength, two for splitting test, and two for 28-days compressive strength test. Euro-code 1 (EN 1992-1-1 2002) and Euro-code 4 (EN 1994-1-1 2004) design requirements has been followed during the design of the solid concrete slab and the composite one. It should be noted that two of the composite slab specimens included the proposed shear connecters whilst the third one was without connectors.

Table 3.3: Mix design proportions and mechanical properties for concrete static test.

Static test mix design	kg/m³	7days Compressive strength (MPa)	7 days splitting strength (MPa)	28 days Compressive strength (MPa)
Cement CEM I 42.5 R	240	26.8	2	32
Fine aggregate 0- 5	1180			
Coarse aggregate 5-12	260			
Coarse aggregate 12-19	440	27.7	2.1	32.6
Water	175			
Superplasticizer	2.45			

Then the specimen was cured under room temperature for seven days and they were watered twice a day under the laboratory temperature. Figures 3.3 and 3.4 show the specimens before and after concreting.

Figure 3.3: Static test specimens before concreting.

Figure 3.4: Static test specimens after concreting.

3.2.1.2 Test Set-up and Loading Procedure of Quasi Static Test

The formwork has been removed after 48 hours and the edge support of composite slab specimens. Yet the edge support of solid slab has been removed on the testing day.

The test has been done on the seventh day after concreting when the concrete reached approximately 86% of its 28 days’ strength. First the cube compression test was done. Then the samples were cleaned and located in the testing frame with the aid of a 5 tons’ mobile crane. Figures 3.5 and 3.6 display the test set-up for the specimen.

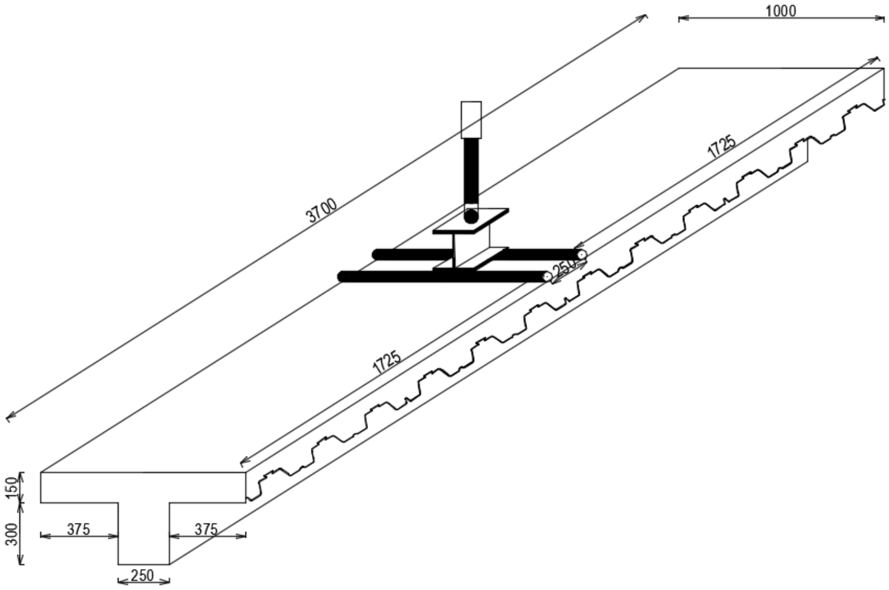


Figure 3.5: Static test load set-up for composite slab.

Three LVDTs have been placed in the mid-span of the beam and the slabs on each side of the beam to monitor the deflection throughout the testing process.

Figure 3.6: Static test load set-up for RC T-beam.

A spreader beam was used to distribute the load via the two 50 mm steel rods that were acting as a line load on the slab. Before concreting the specimens two halves of 5 inches’ pipe has been placed 10 cm from the edges of the beam to insert the supports inside them. The support located in the front of picture in Figure 3.6 was acting as roller support and the one at the other end was acting as pin support since it was inserted inside a channel to prevent its lateral movement while allowing it to rotate.

The load was applied with an increment of 10 kN and every time left constant to observe the developed cracks in the specimen and then increased again. Each test was lasted approximately an hour.

3.2.2 Shear Bond Test by Using the m-k Value Test

The aim of the test was to measure the physical and chemical bond between the concrete and the steel sheet and observe how they would act together under four point loads. The test has been done according to Eurocode 4 (EN 1994-1-1 2004 Annex B.3.). Where, m is a parameter which represent the shear bond due to mechanical interlock and k is a parameter which represent the shear bond due to friction between steel and concrete. EN4 defines two different methods in order to test the shear bond of the slab first one is the m-k method which was used during the test, second one is partial connection method which it should be used with ductile longitudinal shear behavior.

A set of six different specimens has been prepared and tested. Three samples with short span (SS) of 2 m and three samples with long span (LS) of 4 m, with shear span of 450 mm and 950 mm, respectively. The galvanized steel sheet has been obtained from the manufacturer with the required length and concreted in the structures laboratory by using C25 concrete. Figure 3.7 shows the cross section with the dimensions in mm of the concrete slab composite with steel deck.

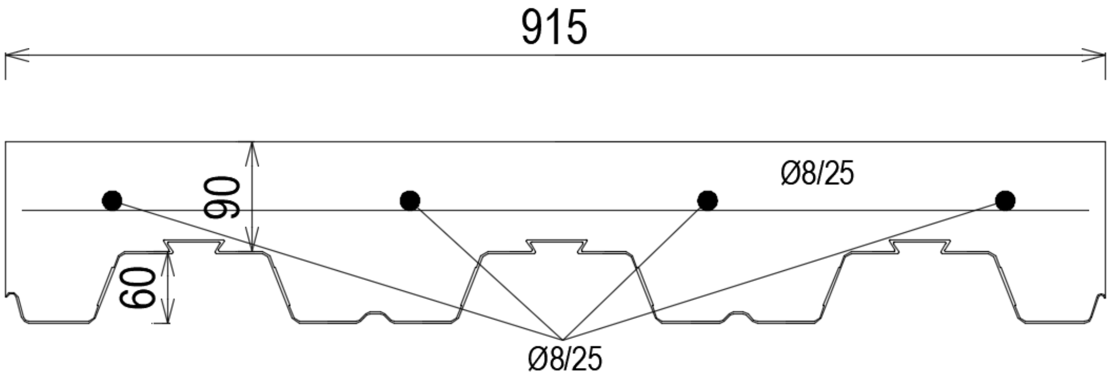


Figure 3.7: Cross-sectional details for m-k test specimens.

The total slab thickness was 150 mm with a width of 915 mm. The formwork has been prepared for the edges of the slab to make sure they are level for the required thickness. Then the rebar’s set in place. After that ready mixed concrete was used and then compacted by using vibrator. The surface of the steel sheet was cleaned before concreting and left as rolled condition. Table 3.2 below show the mix design for the C25 concrete and concrete main strength properties.

Table 3.4: Mix design proportions and mechanical properties for the concrete m-k test.

m-k test mix design	kg/m³	7days Compressive strength (MPa)	7 days splitting strength (MPa)	28 days Compressive strength (MPa)
Cement CEM I 42.5 R	240	27.9	2	32.5
Fine aggregate 0-5	1180			
Coarse aggregate 5-12	260			
Coarse aggregate 12-19	440	27.8	2	32.2
Water	175			
Superplasticizer	2.45			

3.2.2.1 Material Properties and Preparation of Samples for m-k Test

The specimens have been cured for seven days by showering them twice a day and the concrete samples has been cured by the same way Figures 3.8 and 3.9 show the specimens before and after concreting.

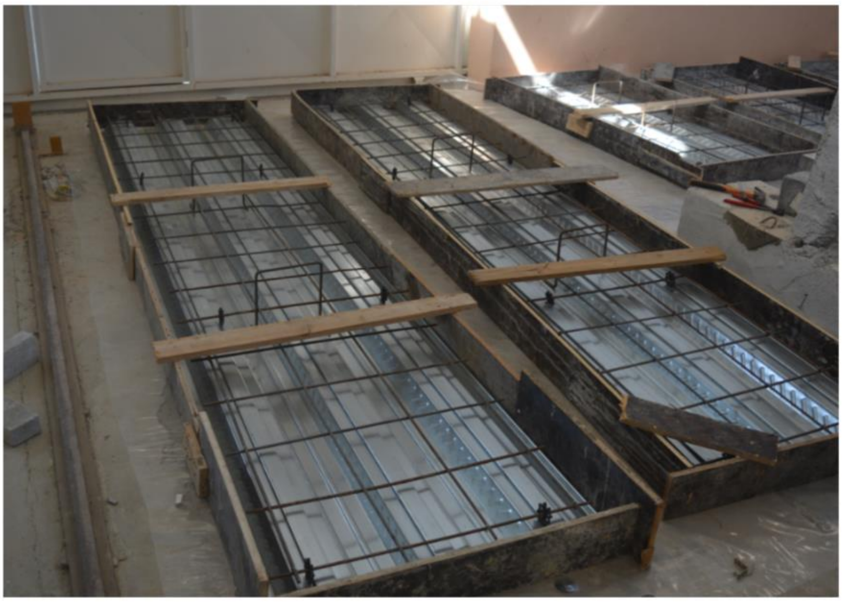


Figure 3.8: m-k test specimens before concreting.

Figure 3.9: m-k test specimens after concreting.

3.2.2.2 Test Set-up and Loading Procedure for m-k Test

In the seventh day after concreting the specimen has been cleaned, prepared and located in the testing frame. A simply supported slab condition has been provided by welding an equal angle to the steel sheet which then was inserted into a channel to work as a pin support. On the other hand, the roller support has been provided by welding a 50 mm steel rod to the steel test support. Figures 3.10 to 3.12 show the test set up.

The load has been subjected to a spreader beam that transfer it as a point load to another two spreader beams which acting as a line load on the slab. Five LVDT transducers has been used one to monitor the mid span deflection during the crushing process, two under each line load, and two to measure the end slip which can define the behavior of the slab.

Figure 3.10: Load set-up for m-k test short span specimen.

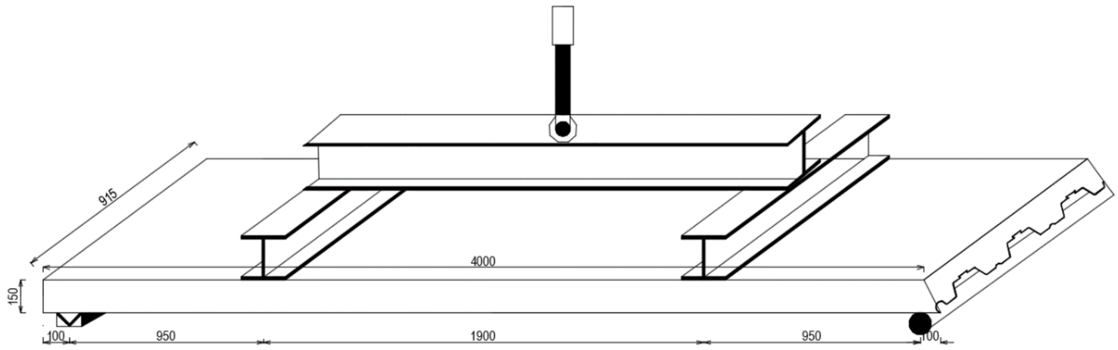


Figure 3.11: Dimensions and load set-up for m-k test.

The expected failure load has been calculated for both cases by using Eurocode 4 1-1 clause 9.7.2.6 load carrying capacity equation for composite slab. First sample of both long span and short span has been subjected to static load with a load increment of 10 kN for the short span and 5 kN for the long one. The failure occurred in an hour time.

Figure 3.12: Load set-up for m-k test long span specimens.

The other two specimens were subjected to a cyclic load with 500 cycle between 0.2W and 0.6W where W is the failure load of the first sample plus its self-weight and the weight of the spreader beams. Then the load has been increased gradually till failure which was occurred after around four hours’ from the start of testing.

3.2.3 Slip Capacity Test (Push-of Test)

In composite beam the push test is required to investigate the effectiveness of the new type of shear connecter to guarantee the composite action between the concrete and the steel component. In this case it was a reinforced in-situ concrete beam which carried a composite slab, and the test was carried out to analyze the developed stresses and internal forces between the beam and the slab. In order to do so the push test was carried out by using four different test cases in conformity with Euro-code 4 annex B.2. In Case1 (SC-FR) the beam, and slab had reinforcement and there was a proposed connector. In Case2 (SC-SR) beam and slab had reinforcement but without connectors. In Case3 (SC) beam had reinforcement but slab had no reinforcement and connector. In Case4 (SC-Con) beam had reinforcement with connector and slab had no reinforcement. Thus the tests were carried out in order to investigate which component will influence the slip capacity and the failure mode.

3.2.3.1 Material Properties and Preparation Samples for Push-of Test

Since the capacity of the hydraulic jack was limited to 500 kN the dimensions, reinforcement and the concrete strength of the specimen has been modified until the maximum load capacity was within the maximum capacity of the hydraulic jack to be able to load the specimen to failure. Then a series of 12 samples with four different arrangements has been prepared. The formwork and the reinforcement has been arranged and then a trans-mixer has been brought to the laboratory to concrete the specimens. Specimens were casted horizontally for both top and bottom slabs as required in the Eurocode 4. Six different concrete samples has been taken from the trans-mixer to test them on the testing day for compressive and tensile strength. Table

3.3 shows the concrete mix design and the compressive strength properties for the slip tests.

Table 3.5: Mix design proportions and concrete compressive strength for slip capacity test.

Slip test mix design	kg/m³	7days Compressive strength (MPa)	28 days Compressive strength (MPa)
Cement CEM I 42.5 R	180	6.8	9.3
Fine aggregate 0-5	1290		
Coarse aggregate 5-12	250	7.1	8.9
Coarse aggregate 12-19	340		
Water	207	7	10.1
Air-Entrainer	0.5		

Figures 3.13 to 3.16 show the specimen’s reinforcement, cross section, dimensions and view before and after concreting.

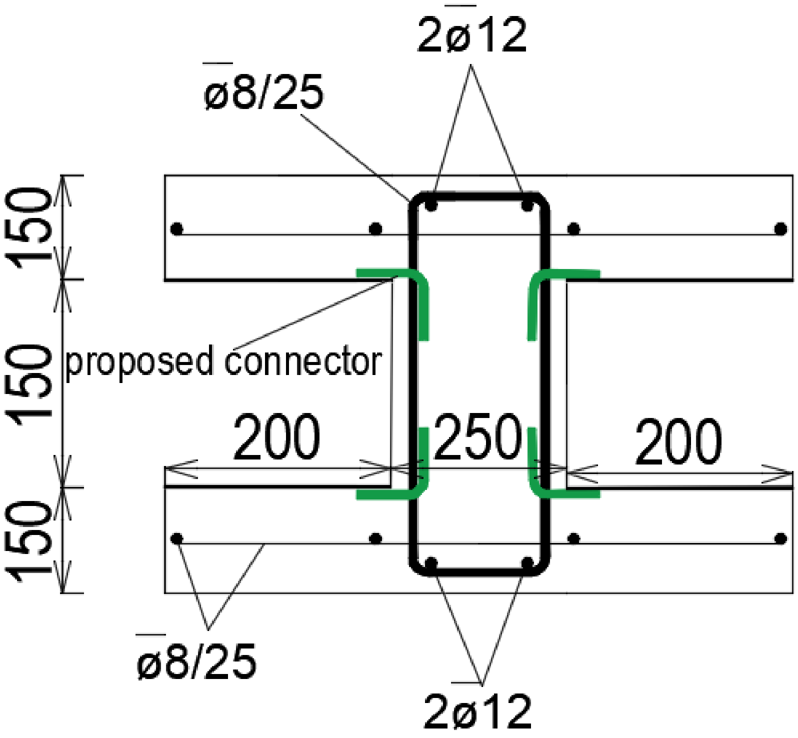


Figure 3.13: Cross-sectional dimensions and reinforcement for specimen SC-FR.

Figure 3.14: View of slip capacity specimen before concreting.

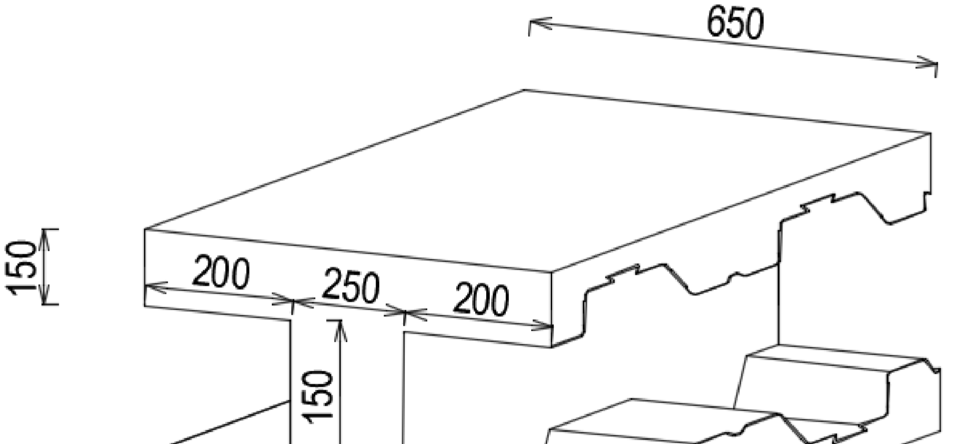


Figure 3.15: Dimensions and 3-D view of slip capacity specimen.

Figure 3.16: Slip capacity specimens during curing process.

The form was opened the second day after concreting. Further, the curing method was done by showering the samples twice a day under the laboratory conditions.

3.2.3.2 Test Set-up and Loading Procedure for Push-of Test

In the seventh day after concreting, the samples were first cleaned, then transferred to the test frame. Figure 3.17 shows the test set-up for the samples.

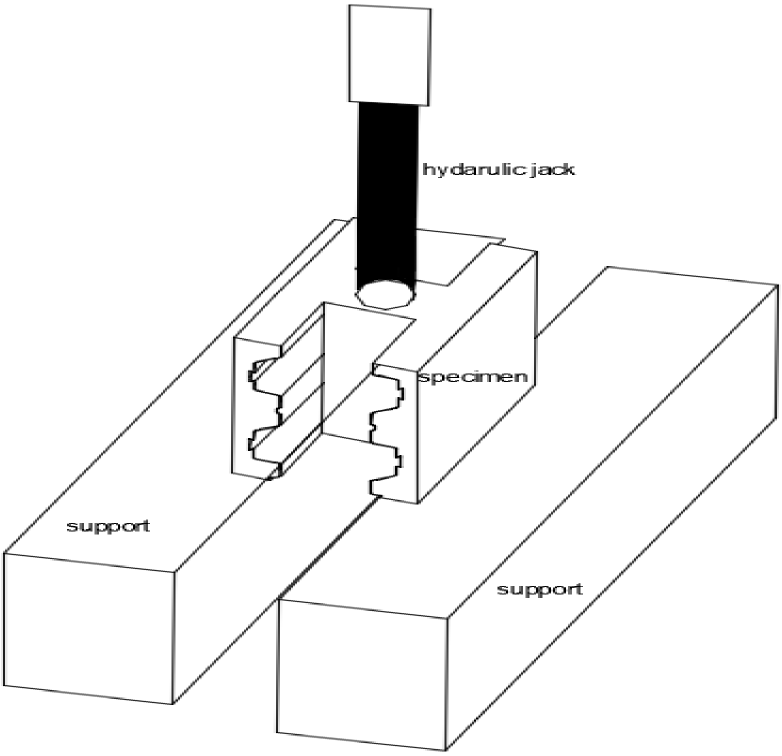


Figure 3.17: Test set-up for slip capacity specimen.

The load has been applied with a gradual increment. Then cycled 25 times between 5% and 40% of the failure load which has been calculated earlier. Then the load was increased until failure with progressive increment and failure reached in around 20 minutes' time. The displacement of the slabs and beam has been monitored through LVDTs located on the specimens throughout the test.

Chapter 4

EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1 Introduction

Total of twenty-two specimens have been tasted in this thesis. Four specimens were under a four-point load static test to evaluate the behavior of the composite slab carried by reinforced concrete beam under flexural load then were compare it with a control sample as traditional concrete solid slab. Six samples were tasted to evaluate the shear bond by m-k method for the locally available material in North Cyprus and Turkey. After that a series of twelve samples has been tasted under the push-of test to assess the slip capacity which is usually develops between the composite beam and the composite slab in the shear transfer zone table 4.1 shows the definition and properties for each specimen.

Table 4.1: Definition and properties for each specimen.

test	Abbreviation	Definition	Proporties
Static test	CS	Composite slab	No shear connector
	CS-SC1.2	Composite slab	Shear connector
	SS	Solid concrete slab	Traditional slab
m-k test	mk-LS1s	Long shear-span	Static load only
	mk-LS2.3c	Long shear-span	Cyclic load crushed by static load
	mk-SS1s	Short shear-span	Static load only
	mk-SS2.3c	Short shear-span	Cyclic load crushed by static load
Slip capacity test	SC-FR1.2.3	Slab reinforcement	Shear connector
	SC1.2.3	No slab reinforcement	No shear connector
	SC-SR1.2.3	Slab reinforcement	No shear connector
	SC-Con1.2.3	No slab reinforcement	Shear connector

4.2 Static Test

4.2.1 Continuous Composite Slabs Carried by RC Beam

Figure 4.1 shows the load versus mid-span deflection for three different composite slab samples. All samples exhibited similar behavior when subjected to the same load conditions. The load versus mid-span deflection graph of four different samples with three different cases exhibit a linear portion (elastic) then a non-linear portion (plastic) followed by the flexural failure.

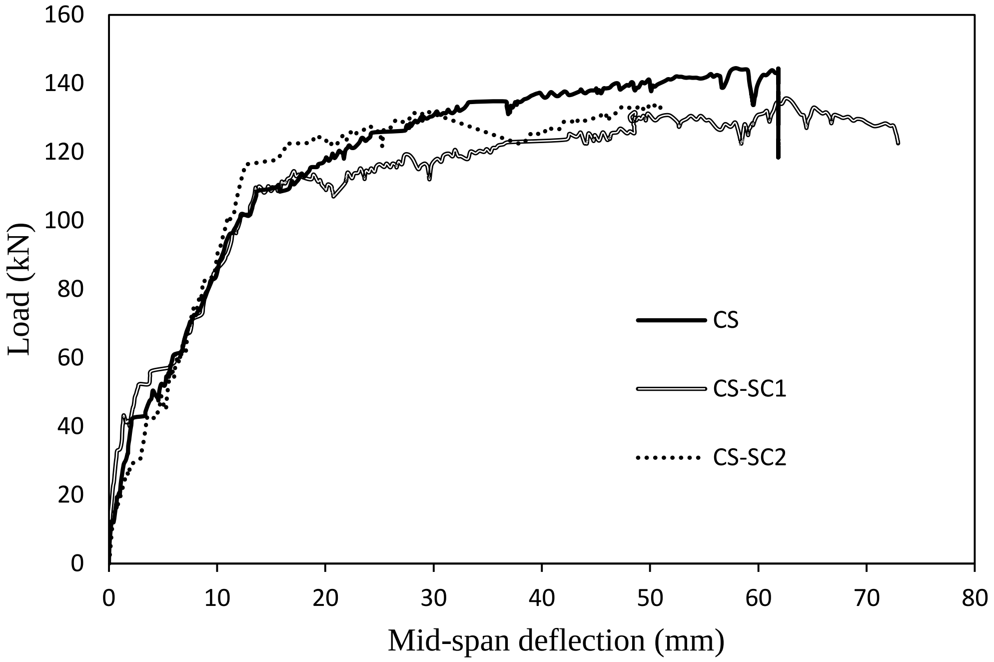


Figure 4.1: Load versus mid-span deflection for three different composite slabs samples.

All three specimens failed under approximately the same load. Sample CS failed under 145 kN with a total deflection of 62 mm. Elastic portion ends at around 110 kN with an average crack width of the beam 3.9 mm at flexural failure. From 0-65 kN no cracks were developed in beam and slabs. After 65 kN load flexural cracks started to develop around the pure bending region of the beam. With the load increment, the number of cracks, their length and width was also increased along the beam depth. When the load reached 110 kN load the beam cracks continued through the slab depth. Eventually the cracks from both sides met in the middle of the slab within the pure bending zone at the failure point with a sudden reduction of the load and an increment of the mid-span deflection. Figures 4.2 and 4.3 show the deformed shape of specimen at failure.

Figure 4.2: Cracks on the reinforced concrete beam after failure of specimen CS.

Figure 4.3: Longitudinal shear of the slab in the zone of pure-bending at the failure load of specimen CS.

For both specimens CS-SC1 and 2, despite their similarities, they had differences in their behavior. CS-SC1 sample showed longer elastic linear portion than CS-SC2. They had approximately the same failure load but with less total mid-span deflection.

On the other hand, both specimens had the same failure mode. Figures 4.4 and 4.5 show the failure mode of both specimens.

Figure 4.4: CS-SC1 specimen beam and slab cracks after failure.

Figure 4.5: CS-SC2 specimen beam and slab cracks after failure.

4.2.2 Continuous Solid Slabs Carried by RC Beam.

The SS sample, as control sample, had 20% more concrete and 30% more reinforcement than the CS-SC1 and the other 2 samples, behaved in a very similar manner as the composite slab sample. The elastic load in solid slab was larger than composite one with a value of 120 kN as oppose to 110 kN and the total mid-span deflection was 47.7 mm as oppose to 62 mm. From 0-60 kN load there were no cracks on the beam. However, from 60-80 kN numerous thin flexural cracks started to develop on the beam. After 90 kN load the beam cracks moved into the slab and then the failure occurred at 146.2 kN in the pure bending zone with an average crack width of 13.5 mm (Fig 4.6).

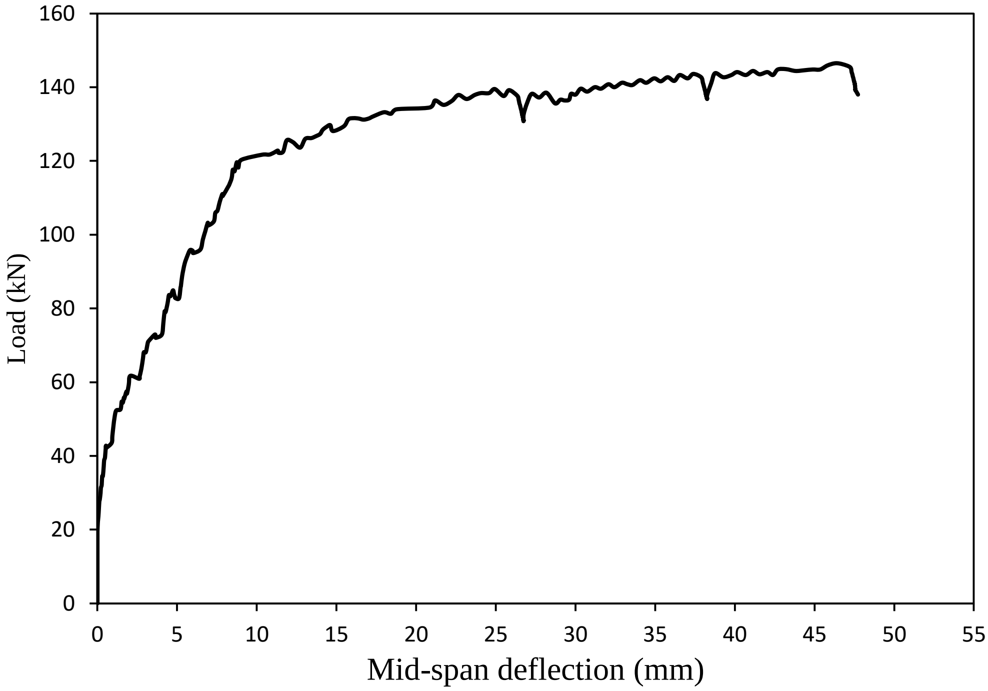


Figure 4.6: SS specimen load versus mid-span deflection.

Figure 4.7: The failure modes of the SS sample.

4.2.3 Discussion of Results for Continuous Composite and Solid Slabs

Table 4.2 gives the main parameters for each test specimen. It is clear from the Table 4.2 and Fig 4.8 that the composite and solid slab supported by RC beam behaved in a similar manner except that the initial elastic stiffness of the solid slab was higher than the composite one; the elastic load was about 10% higher with elastic mid-span deflection being around 30% lower. On the other hand, the failure load was almost the same whilst the total mid-span deflection corresponding to failure load was 25% more for the composite slab whereas the average crack width was considerably lower for composite slab The SS sample achieved less total mid-span deflection than the CS and CS-SC1 and 2. This could be due to the composite slab having galvanized flexible steel sheet that made the overall slab to have more flexible behavior. In addition, the proposed connector did not play an important role in the flexural resistance of the specimens since specimen CS-SC1 and 2 with connector behaved same as specimen CS. without connector.

Table 4.2: Main load/deflection values for static test specimens.

Specimen	Elastic portion (kN)	Total deflection (mm)	Failure load (kN)	Average Crack-width (mm)
CS	110.0	61.8	144.0	3.9
CS-SC1	118.0	52.0	134.2	4.1
CS-SC2	117.0	72.9	135.6	4.2
SS	120.0	47.7	146.2	13.5

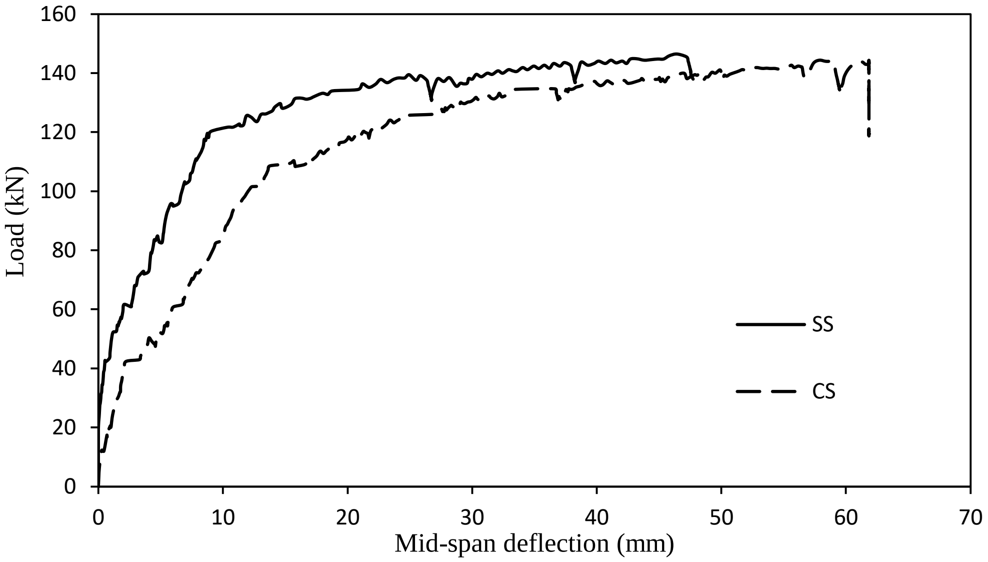


Figure 4.8: Comparison of the load versus mid-span deflection for samples SS and CS.

4.3 Shear Bond Test by Using the m-k Value Test

A total of six samples has been tested to determine the m-k value and find out the behavior of the composite slab. The short span samples behaved in such a manner that the failure was due to the longitudinal shear of the slab which occurred under the line load.

4.3.1 Short Span m-k Specimens

The specimen's mk-SS1s and mk-SS2c were failed under the line load which was close to the pin support. On the other hand, specimen mk-SS3c was failed under the line load which was close to the roller support. Approximately all three specimens failed in the same manner. From 0-60 kN load no cracks were developed. After 60 kN load the longitudinal shear cracks started to develop under the line load and they became wider and longer with the increment of the load. Thus the flexural cracks of the short span specimens were somehow scarce and they developed in the plastic region. The results of mk-SS1s are shown in Figures 4.9 to 4.11 as load versus mid-span deflection, load versus end-slip next to the roller support and load versus end-slip next to the pin support, respectively.

At the specimen’s failure load buckling of the web of the sheet also occurred. So a balanced failure occurred in the specimen’s where the failure of the concrete accompanied by the failure of the sheet. Figure 4.12 shows the buckling of the galvanized sheet web at the failure load. Due to simply supported beam end conditions it is acceptable to have one of the support end-slip being larger than the other support.

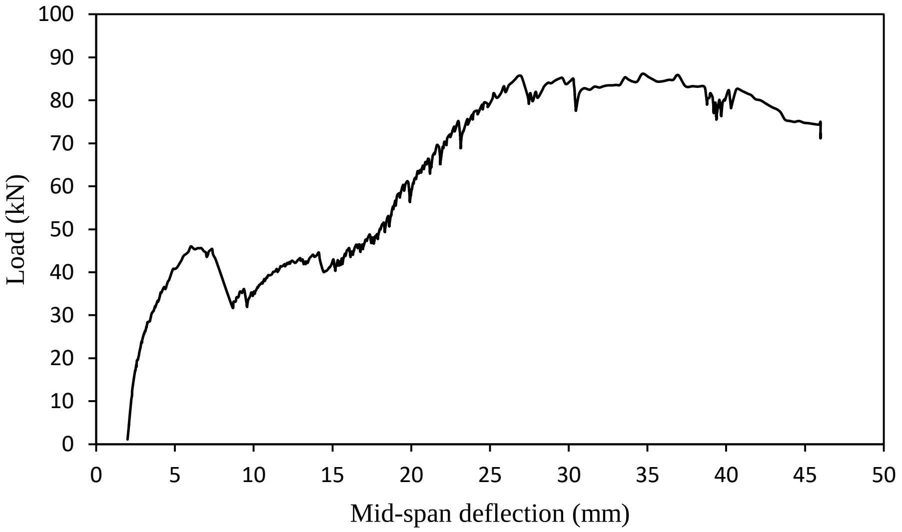


Figure 4.9: Load versus mid-span deflection for specimen mk-SS1s.

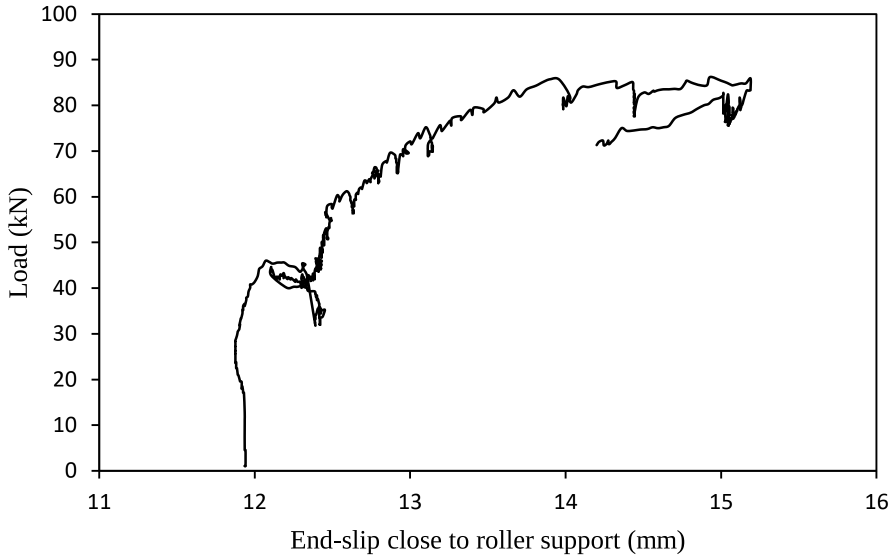


Figure 4.10: Load versus end-slip close to roller support for specimen mk-SS1s.

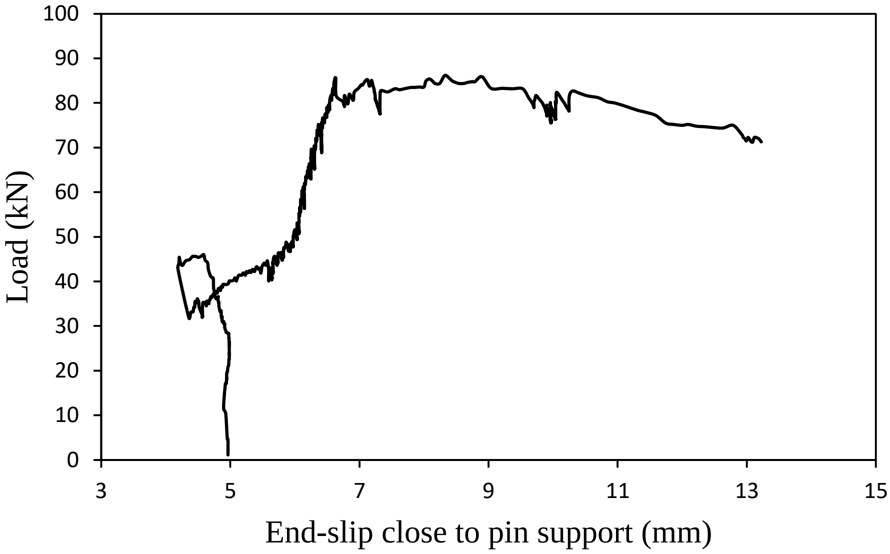


Figure 4.11: Load versus end-slip close to pin support for specimen mk-SS1s.

Figure 4.12: Buckling failure of the steel sheet web.

EN 1994-1-1 2004 requires the measurement of end-slip in order to define the behavior of the slab. Figures 4.13 and 4.14 show the end slip during and at the end of the test.

Figure 4.13: Beginning of end-slip during the test process.

Figure 4.14: End-slip of specimen mk-SS1s after failure.

The failure mode of the slab has been displayed in Figure 4.15.

Figure 4.15: Overall view of mk-SS1s specimen after failure due to the failure at the location of the left line load.

4.3.2 Long Span m-k Specimens

The specimen's mk-LS1s and mk-LS3c failed under the line load which was located close to the pin support and specimen mkLS2c failed under the line load which was located close to the roller support. This could have happened due to some eccentricity occurred during the test set-up. The three specimens failed almost in the same manner. From 0-17 kN load there were no cracks developed but after 17 kN load longitudinal shear cracks started to develop under the line load and they got wider and longer with the increase of the load. In addition, the flexural cracks of the long span slab specimens were more than those of the short span slab case and they developed in the early stage of the loading process. The results of specimen mk-LS1s are shown in Figures 4.16 to 4.18 load versus mid-span deflection, load versus end-slip next to the roller support and load versus end-slip next to the pin support, respectively.

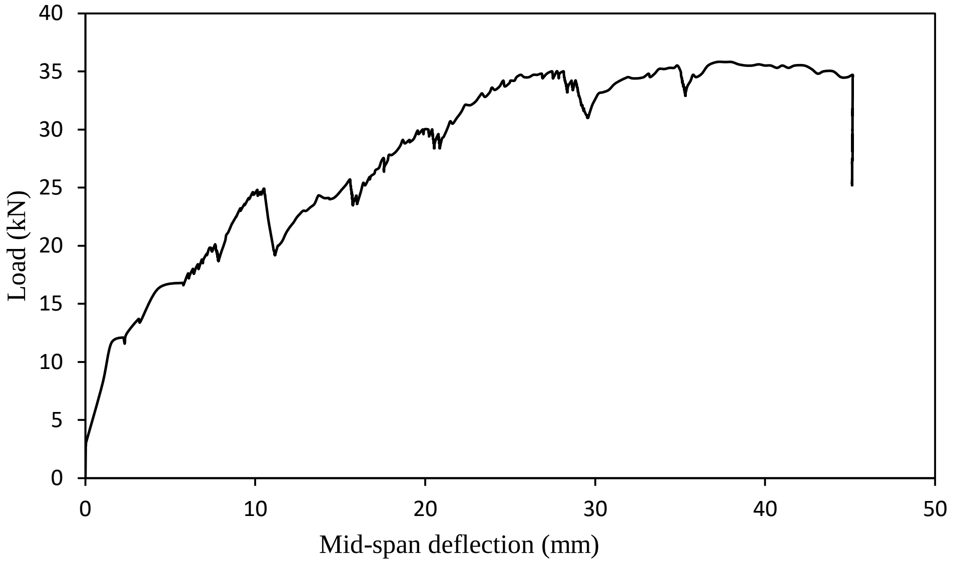


Figure 4.16: Load versus mid-span deflection for specimen mk-LS1s.

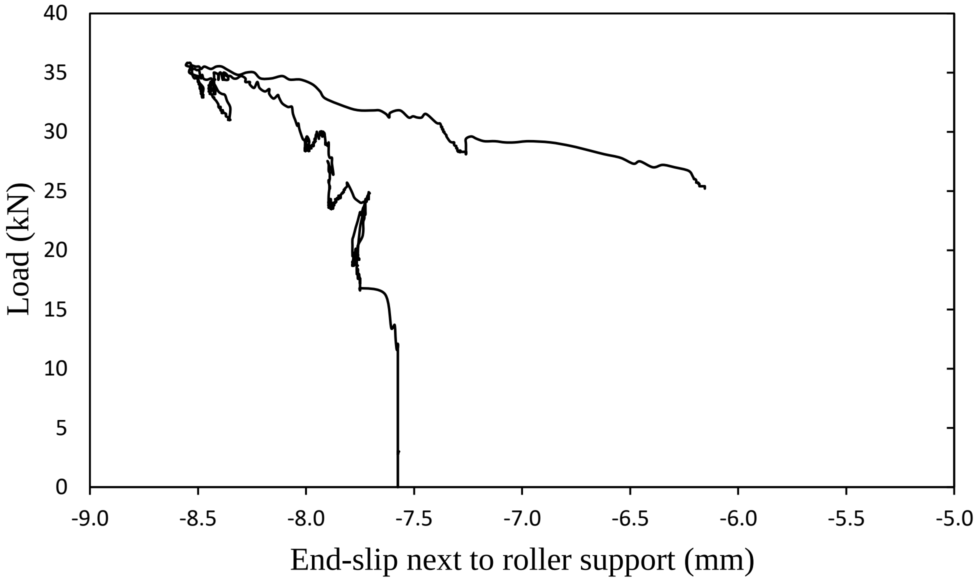


Figure 4.17: Load versus end-slip close to roller support for specimen mk-LS1s.

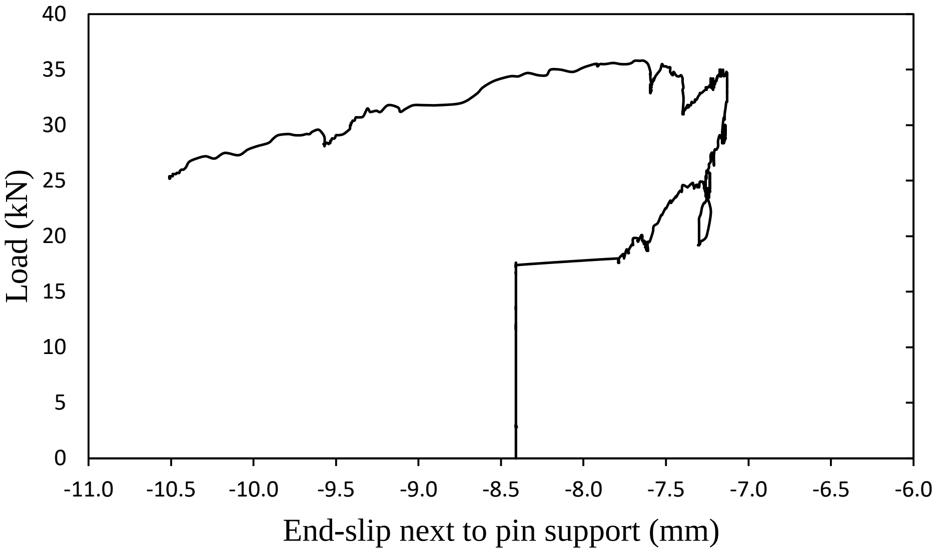


Figure 4.18: Load versus end-slip close to pin support for specimen mk-LS1s.

Despite the fact that the flexural cracks were more in long span specimens than short span one the mode of failure was the same, failure due to the longitudinal shear of the slab. Figures 4.19 and 4.20 show the specimen mode of failure and Figure 4.21 displays the specimen end-slip.

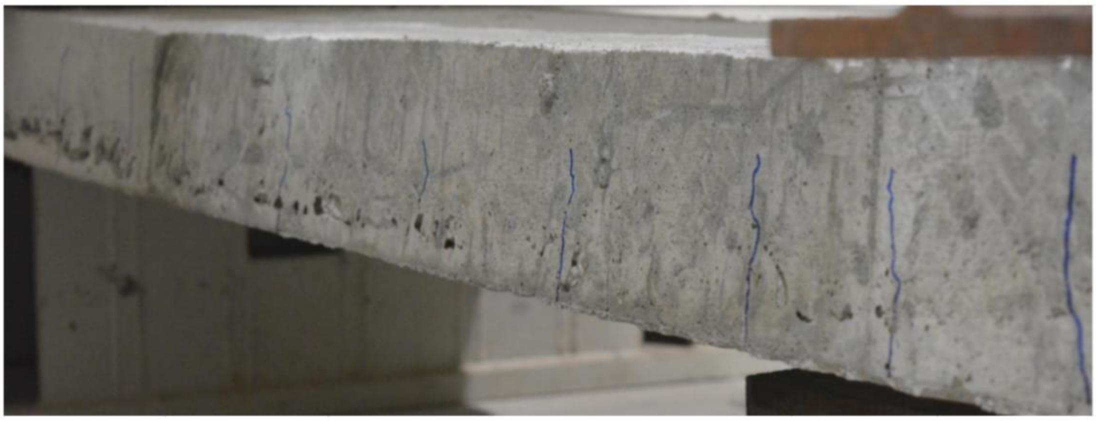


Figure 4.19: Pattern of cracks after failure for specimen mk-LS1s.

Figure 4.20: Longitudinal shear failure mode for specimen mk-LS1s.

Figure 4.21: End-slip after failure for specimen mk-LS1s.

4.3.3 Calculation of m-k Values and Shear Bond Capacity

Tables 4.3 and Table 4.4 present the main parameters which are required to calculate m-k values.

Table 4.3: Main parameters for the calculation of m-k values.

Specimen	W_{dl} (kN)	P_u (kN)	W_t (kN)	$W_{0.1\ slip}$ (kN)	W_t / $W_{0.1\ slip}$	Behavior	V_t (kN)	L_s (mm)	A_p (mm^2)	b (mm)	d_p (mm)
mk-SS1s	5.6	86.0	91.6	51.6	1.8	ductile	45.80	450	1345	915	120
mk-SS2c	6.0	124.0	130.0	70.0	1.9	ductile	65.00	450	1345	915	133
mk-SS3c	5.6	98.0	103.6	51.2	2.0	ductile	51.80	450	1345	915	120
mk-LS1s	11.1	35.8	46.9	28.5	1.6	ductile	23.45	950	1345	915	120
mk-LS2c	11.1	30.0	41.1	28.1	1.5	ductile	20.55	900	1345	915	120
mk-LS3c	11.1	38.7	49.8	27.1	1.8	ductile	24.90	950	1345	915	120

Where:

W_{DL}: is the weight of the specimen including the steel sheet weight and the spreader beams weight.

P_u: is the applied failure load.

W_t: is the sum of W_{DL} and P_u.

$W_{0.1}$: is the load which caused 0.1 mm end-slip plus the self-weight of the specimen.

V_t: is the reaction load which equal to W_t over 2 as the specimens show a ductile behavior.

L_s: is the shear span length.

A_p: is the effective cross-section of the steel sheet.

b: is the width of the specimen.

d_p: is the depth of the specimen from the neutral axis of the steel sheet.

Table 4.4: Values of V_t and A_p for all tested specimens.

Slab Type	V_t/(b.d_p)	A_p/(b.L_s)
mk-SS1s	0.417122	0.003267
mk-SS2c	0.534122	0.003267
mk-SS3c	0.471767	0.003267
mk-LS1s	0.213570	0.001547
mk-LS2c	0.187158	0.001633
mk-LS3c	0.226776	0.001547

Using the above results the characteristic regression line has been drawn as shown in Figure 4.22

$$m = 156.23 \qquad k = 0.0365 \qquad Eq(1)$$

From Figure 4.22 the design relationship for longitudinal shear resistance can be drawn as

$$y = 156.23x - 0.0365 \qquad Eq(2)$$

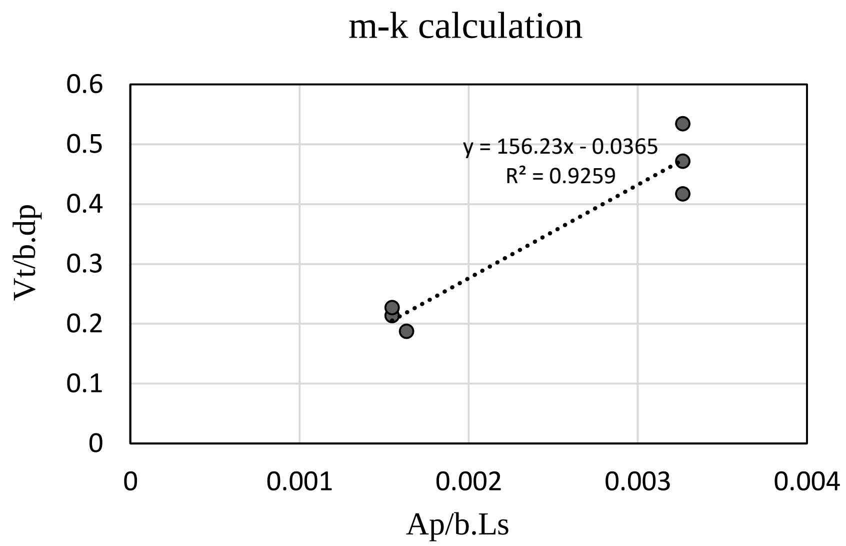


Figure 4.22: Regression line for the calculation of the longitudinal shear relationship.

The shear bond design equation which was suggested by Porter et al (15) has been used

where the shear bond is

$$\tau_{u,R_d} = m\frac{A_p}{b*L_s} + k\sqrt{f_c} \qquad Eq(3)$$

Where,

f_c: is the concrete cylinder strength

Table 4.5 shows the important loads for the specimens with the most noticeable deflections and end-slips.

Table 4.5: Main test loads/ deflection for all tested specimens.

Specimens	Cyclic load	Behavior	V_t (N)	f_c (MPa)	$\tau_{u.Rd}$ (Mpa)	End-slip (mm)	Total deflection (mm)
mk-SS1s	no	ductile	45800	25	0.69	6.0	47.0
mk-SS2c	yes	ductile	65000	25	0.69	3.9	33.0
mk-SS3c	yes	ductile	51800	25	0.69	5.0	30.5
mk-LS1s	no	ductile	23450	25	0.42	3.0	45.0
mk-LS2c	yes	ductile	20550	25	0.44	3.5	54.0
mk-Ls3c	yes	ductile	24900	25	0.42	4.0	46.5

4.3.4 Discussion of Results for m-k Tests

At the beginning of the load increment both galvanized steel deck and concrete were acting compositely together until the load reached to about 70 % of the failure load. Then chemical and physical separation between concrete and the galvanized steel deck started to be clear as the mid-span deflection increased. At this stage the end-slip was also clearly visible.

After the calculation of the m and k has been done the results were compared with other authors to control the applicability of the locally available material as composite slab table 4.6 shows a brief comparison with other authors.

It is clear that in table 4.6 the values which has been calculated for m-k are reasonably acceptable, even though the main parameters were not exactly similar to the present study.

Table 4.6: comparison with other authors in terms of m-k values

Ref	fc (Mpa)	Ls (mm)	Ap (mm²)	b (mm)	dp (mm)	Thickness mm	m	k
[5] Ac	38	575	1003	927	103	140	90.95	0.043
[5] Ac	38	1000	1003	927	143	180	90.95	0.043
[5] Aw	38	575	1003	927	103	140	74.41	0.080
[5] Aw	38	1000	1003	927	143	180	74.41	0.080
[6] P3623 ECC	64	450	1016	960	51	100	345.01	0.037
[6] P3623 SCC	51	450	1016	960	51	100	313.21	0.040
[6] P2432 ECC	66	450	1131	620	76	125	138.17	0.016
[6] P2432 SCC	56	450	1131	620	76	125	136.17	0.016
Result	27.9	450	1345	915	120	150	156.23	0.037
Result	27.9	950	1345	915	120	150	156.23	0.037

Unfortunately, hydraulic jack with hand pump was used for loading the specimen. Hence it was not possible to apply the load at 5000 cycles which is recommended by Eurocode 4. Only 500 cycles were applied and it was noticed that applying load through cycles did not cause noticeable difference in both max failure load and mid-span deflections. Furthermore, Figure 4.23 shows the difference between the cyclic and monotonic loading for mid-span deflection. Figure 4.24 illustrates the end-slip for sample mk-LS2c with cyclic load.

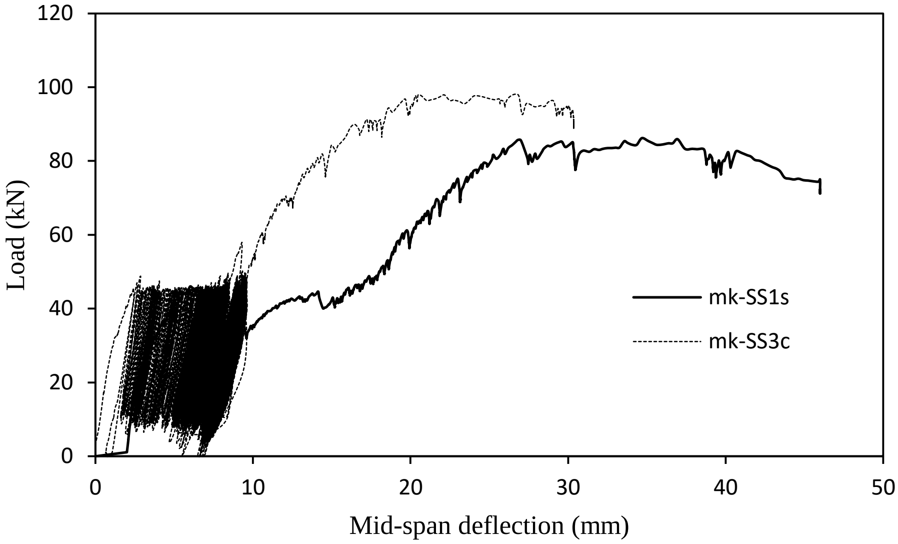


Figure 4.23: Comparison of load versus mid-span deflection for mk-SS1s and mk-SS3c.

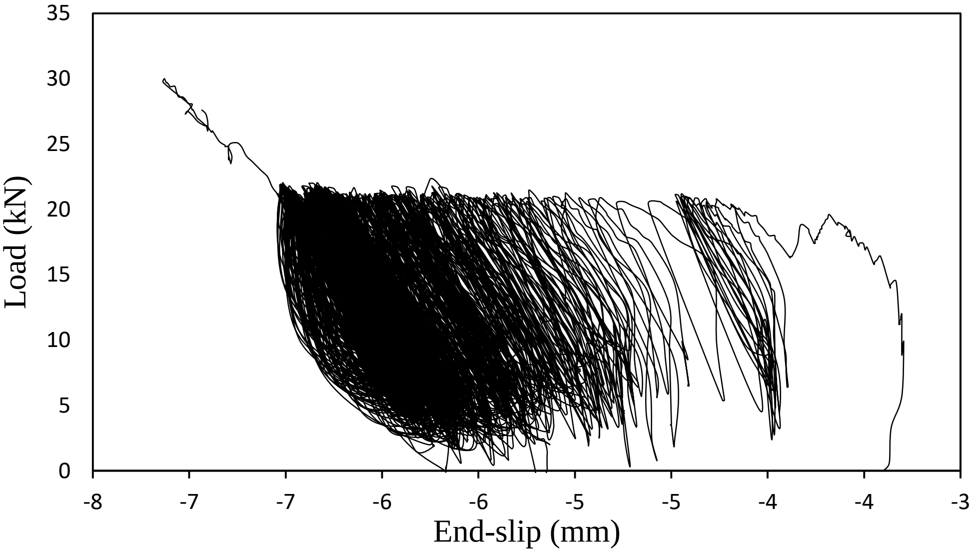


Figure 4.24: Load versus end-slip for specimen mk-LS2c.

4.4 Slip Capacity Test (Push-of Test)

A total of 12 specimens has been tested as per the requirements and procedures of Eurocode 4. Table 4.7 gives the details of the specimens which were divided into four groups.

Table 4.7: Properties of slip capacity test series.

SC-FR1	yes	yes
SC-FR3		
SC-SR1	yes	no
SC-SR2		
SC-SR3		
SC1	no	no
SC2		
SC3		
SC-Con1	no	yes
SC-Con2		
SC-Con3		

Presence of slab reinforcement and proposed connector were the variable to obtain the four different group of specimens. The aim was to find out significance of component that plays the main role in connecting the concrete beam to the slabs. This was similar to the investigation carried out on the composite beam connection to solid or composite slab.

For the SC1 group of specimens the shear cracks started to develop at a load of 200 kN in the zone between the beam and the adjacent slabs. After the load of 250 kN longitudinal shear cracks started to appear along the slabs. The cracks started at the bottom of the slabs and they became longer and wider with the increase in load. The failure mode was both due to the longitudinal shear of the slab and the local crushing of the beam under the load. Figure 4.25 shows the load versus longitudinal slip for all SC-FR group of specimens.

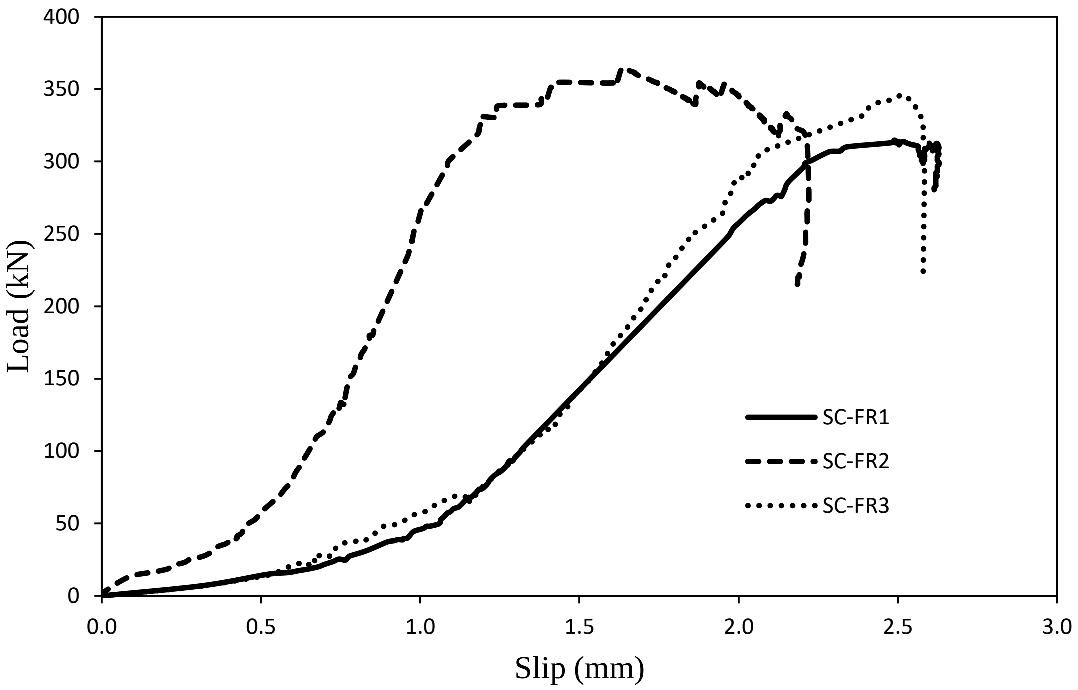


Figure 4.25: Load versus longitudinal slip of specimen series SC-FR.

The elastic behavior of the specimens' end at around 95 % of the failure load with a small deviation due to the natural behavior of the concrete. Figures 4.26 and 4.27 show the mode of failure of the specimens.

Figure 4.26: Failure mode of specimen series SC-FR with local crushing of the beam.

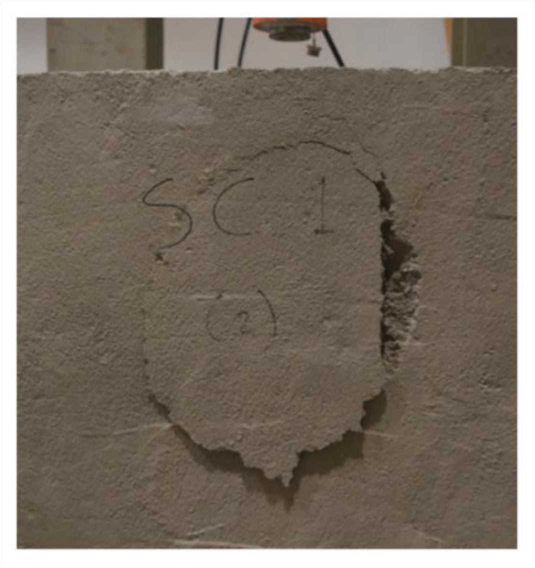


Figure 4.27: Longitudinal shear of the concrete slab for specimen series SC-FR.

In group SC-SR the failure mode was identical to group SC-FR since no difference has been observed during the crushing process. Both groups of samples failed approximately at a similar load value too. Figure 4.28 displays the load versus longitudinal slip relationship of the group and Figures 4.29 and 4.30 show the failure mode of the specimens.

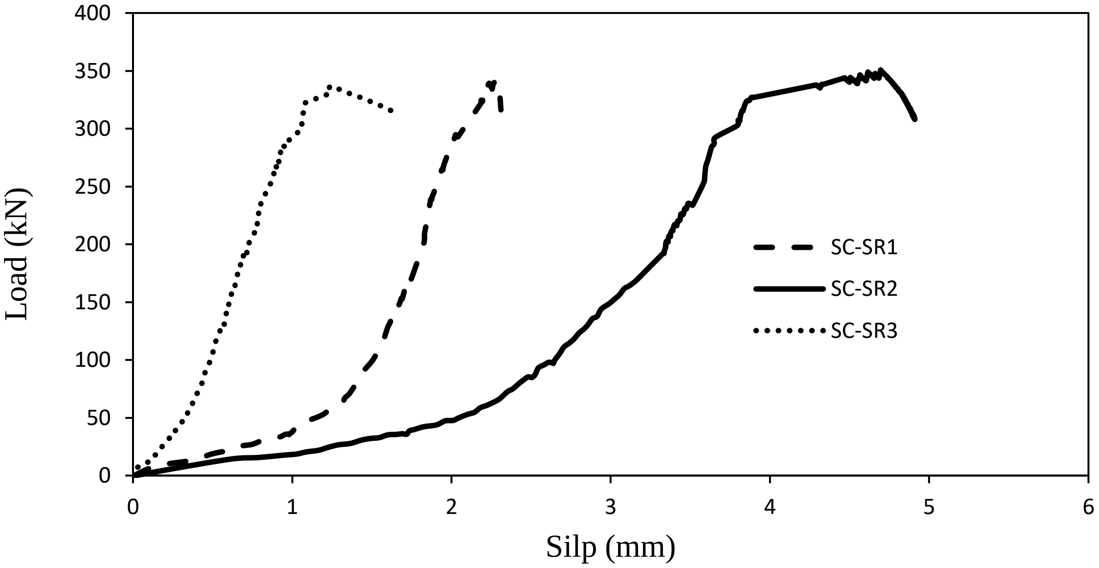


Figure 4.28: Load versus longitudinal slip for specimen series of SC-SR.

Figure 4.29: Local shear between the slabs and the beam specimen series of SC-SR.

Figure 4.30: Longitudinal shear of the slab specimen series of SC-SR.

Groups SC and SC-Con they almost have the same failure modes where the longitudinal shear cracks started to appear at a load between 180 to 200 kN along the slabs at the shear zone between the beam and the slabs. Then a sudden failure occurred as the beam separated from either one or both of the slabs which were carried by the beam. Furthermore, a total separation of the concrete from the steel sheet has been observed at the failure point. Figures 4.31 and 4.32 represent the load versus longitudinal slip relationship for groups SC and SC-Con, respectively.

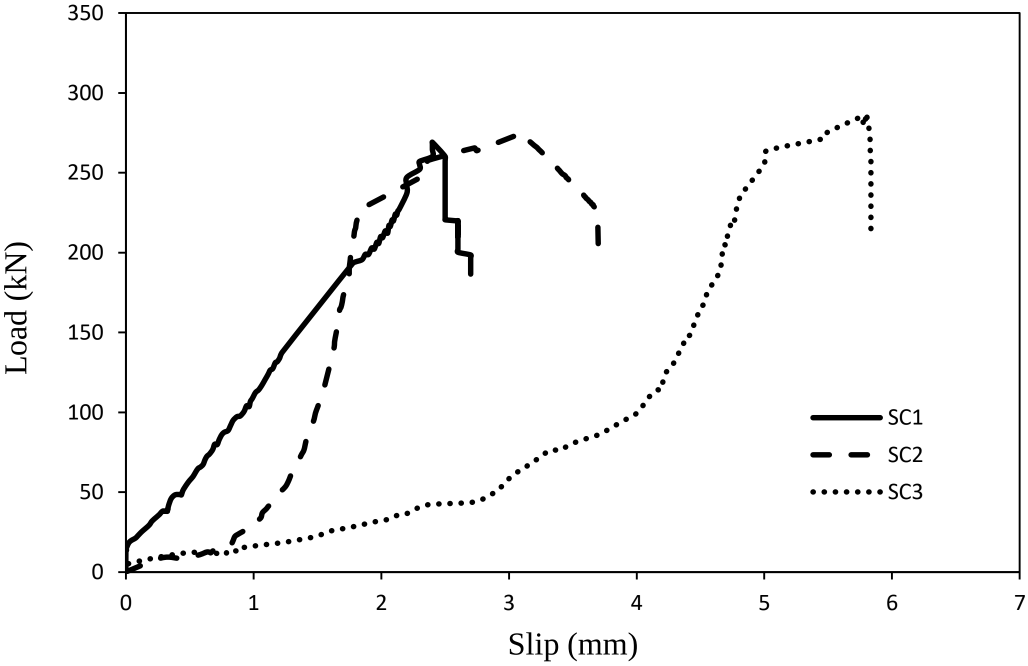


Figure 4.31: Load versus longitudinal slip specimen series of SC.

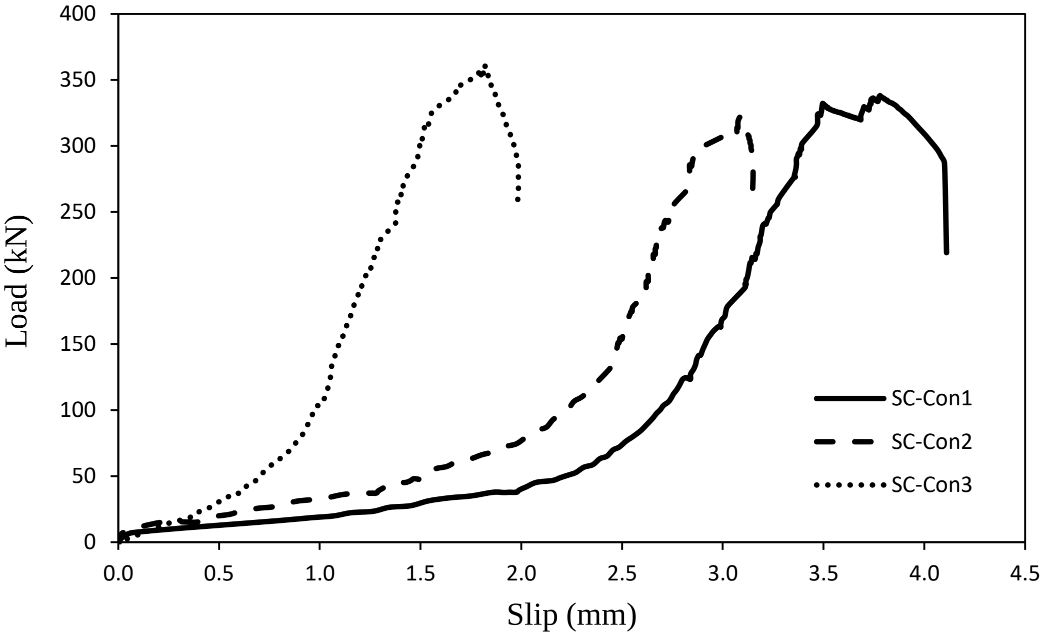


Figure 4.32: Load versus longitudinal slip for specimen series of SC-Con.

It is obvious that the only difference between group SC and SC-Con is the load carrying capacity which was larger for group SC-Con. Moreover, SC-Con group showed more uniform load versus longitudinal slip relationship. Yet both of them behaved like plain concrete when stress-strain relationship was considered. Figures 4.33 and 4.34 show the mode of failure of group SC, and SC-Con, respectively.

Figure 4.33: Mode of failure for specimen series of SC-Con.

Figure 4.34: Mode of failure for specimen series of SC.

For group SC-Con the proposed connector diameter has been measured before and after the test. No change in diameter has been recorded in the diameter for two of the specimens. Figure 4.35 displays the connector after the test.

Figure 4.35: Shape of connector after failure specimen series of SC-Con.

Evaluating the results of the experiments carried out for the four different cases the outcome can be summarized as follows.

In group SC-FR and SC-SR the load carrying capacity was larger than the other two groups which represent the influence of slab reinforcement. The existence of slab reinforcement increased the overall load carrying capacity. Furthermore, the slab reinforcement provides ductility to concrete which leads to group SC-FR and SC-SR specimens exhibiting more ductile failure than group SC and SC-Con where specimens went through a brittle mode of failure like plain concrete. Figure 4.36 compares all different cases in terms of load versus slip capacity.

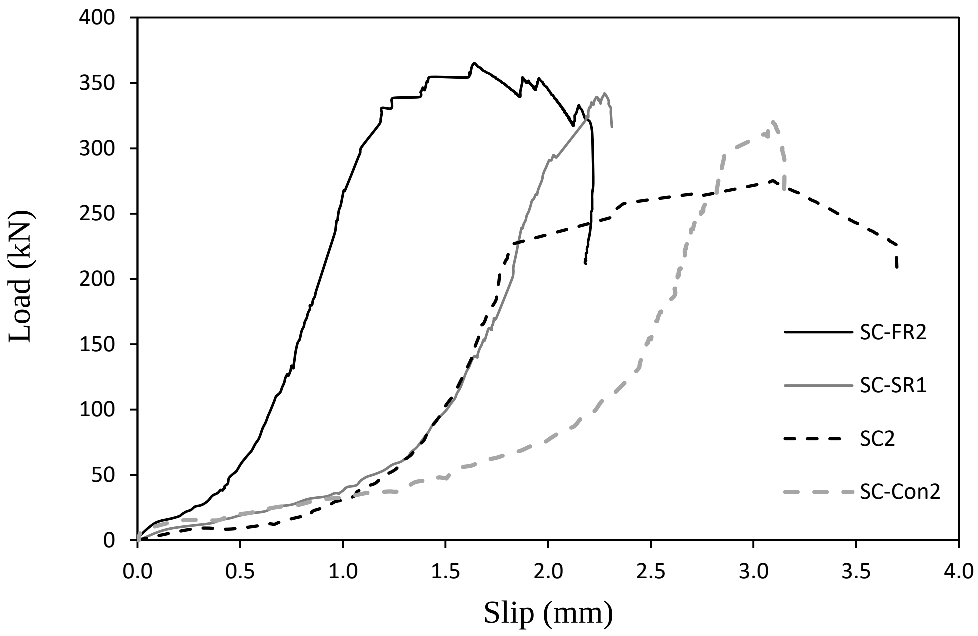


Figure 4.36: Load versus longitudinal slip for a specimen from each series.

According to Eurocode 4, which requires 6 mm slip for ductile behavior, all cases had brittle behavior. Ductile failure does not exist in this structural system as the connector does not play any role in either load carrying capacity or total slip. This behavior has been predicted with an understanding of the nature of reinforced concrete structures. This can be an advantage of the new system since slip capacity is one of the major concern in designing composite beam with slab composite with galvanized steel deck. Despite the fact that proposed connector had slightly increased the load carrying capacity of the specimen more investigations should be done in future with different connector and different type of concrete to try to understand the behavior and level of ductility of such systems.

Chapter 5

COMPARISON WITH OTHER SLAB SYSTEMS

This chapter compares the use of five different floor slabs as the variables within the same reinforced concrete building frame. First case is the building with two-way concrete solid slab. The second case is the building with one-way concrete solid slab. The third case is the building with composite slab carried by reinforced concrete beam. The fourth case is the building with one-way joist floor. The fifth case is the building with beamless flat slab. The building consists of seven stories with the same grids in all three cases and it was subjected to gravity load only. Figure 5.1 shows the typical floor plan of the building in two-way slab case, one-way joist floor case and flat slab case. Figure 5.2 displays a typical floor plan of the building with one-way slab composite with steel deck.

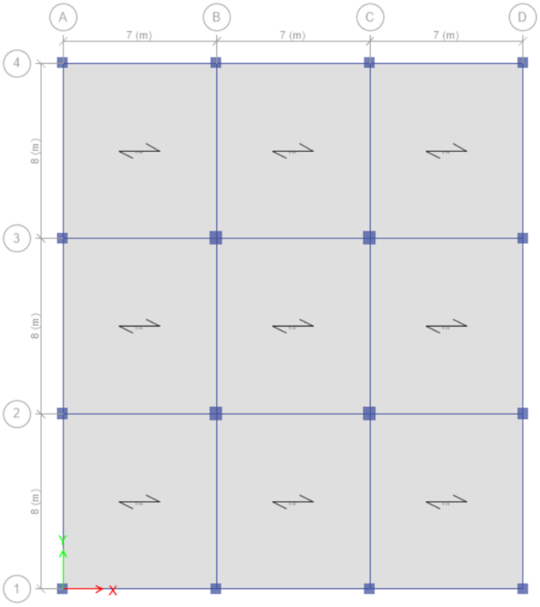


Figure 5.1: Plan view of RC building with two-way solid slab.

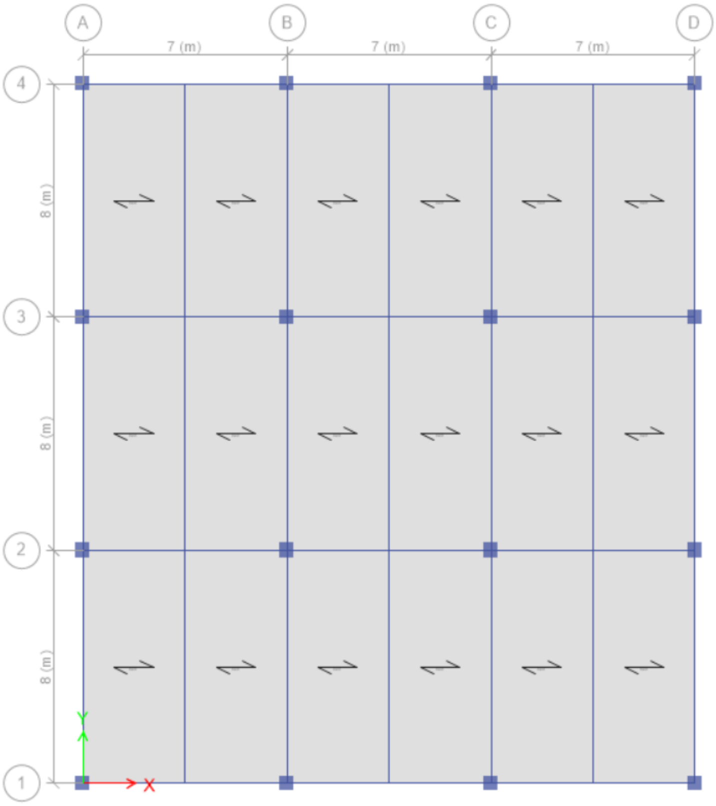


Figure 5.2: Plan view for both one-way solid slab and composite slab.

The thicknesses of the slabs were 18, 12, 12, 28 and 28 cm for two-way, one-way concrete solid slab, composite slab, one-way joist floor and flat slab, respectively. All thicknesses have been selected in accordance to the span length in all cases. The assumed super imposed loads are same in all cases G= 1.2 kN/m² as slab finishing load and Q= 3.0 kN/m² as imposed load with an ultimate load combination of 1.35G+1.5Q. In all cases the reinforcement ratio of the columns was fixed to 1%. Table 5.1 displays the floor slab section dimensions for each case.

Table 5.1: Column and beam dimensions for the RC buildings.

Slab type	Thickness (cm)	Primary beam (cm)	Sec.beam (cm)	Exterior columns (cm)	Interior columns (cm)	Story height (m)
Two-way solid	18	30/60	30/60	50/50	60/60	3.2
One-way solid	12	25/45 25/50	25/45	50/50	55/55	3.2
Composite	12	25/45 25/50	25/45	50/50	50/50	3.2
one-way joist	28	60/28	20/28	50/50	60/60	3.2
flat slab	28	/	/	50/50 55/55	65/65	3.2

The cross sectional dimensions for the beams and the columns were chosen to satisfy the required loading capacity for beams and columns. A brief comparison has been carried out between the five buildings by considering building weight, concrete amount in each floor, the whole building, shuttering work for each floor and the total building, and amount of reinforcement in slabs only. Tables 5.2 to 5.4 give details of the materials for all five buildings.

Table 5.2: Quantity of materials of the five buildings.

Type of slab	Formwork			Concrete		Reinforcement
	Column (m^2)	Beam and slab (m^2)	Steel sheet (m^2)	Column (m^3)	Beam and slab (m^3)	Slab rebar (ton)
Solid two-way	87.4	724	0	14.5	123.2	3.2
Solid one-way	85.3	739	0	14.0	90.7	2.5
Composite	83.2	235	504	13.0	71.8	1.2
one-way joist	102.0	531	0	15.9	106.6	5.8
flat slab	102.0	531	0	15.8	144.0	9.1

Table 5.3 shows the comparison between the three buildings by considering the amount of material for the whole building.

Table 5.3: Comparison between the five buildings in terms of material and weight.

Type of slab	Building weight (kN)	Total concrete (m^3)	Total shutterig (m^2)	Slabs rebar (ton)	Steel sheet (m^2)
Two-way solid	27673.8	963.9	5679.8	22.4	0
One-way solid	22134.7	732.9	5770.1	17.5	0
Composite	20242.0	593.6	2227.4	8.4	3528
one-way joist	29494.8	857.5	4431.0	40.6	0
flat slab	31668.6	1118.6	4431.0	63.7	0

It is clear that the use of composite slab lead to building being lighter than the one-way solid and two-way solid slab by 8.6% and 27%, respectively. This is due to the reduction in concrete amount which is around 19% for building with one-way solid slab and 38.4% for building with two-way solid concrete slab. The speed of construction period relates to the reduction in shuttering work and the un-propped use of the composite slab which can be easily installed with less workmanship. Furthermore, there is less rebar work since composite slab needs wire-mesh only which comes ready to the construction site. All this speeds up the construction period However, the price of steel sheet could be higher than the traditional form work which depends on the locally available material and the workmanship cost. On the other hand, the savings in concrete, rebar, and workmanship may balance the additional cost which comes from the use of the steel sheet.

Chapter 6

CONCLUSION AND RECOMMENDATION FOR FUTURE WORK

A total of 22 samples has been tasted, where four specimens were used for static test, three with composite slab carried by reinforced concrete beam and one control sample as solid concrete slab carried by the same beam. Six specimens were designed and tested considering the m-k value to determine the shear bond resistance which develop in composite slab between concrete and galvanized steel deck for the locally available material in North Cyprus and Turkey. Twelve specimens were tested to investigate the slip capacity resistance for the new system which consist of composite slab carried by reinforced concrete beam. A parametric study was carried out to define the importance of each component in transferring the shear from the slab to the beam. This followed by a comparison of building weight and material usage between the composite slab and the traditional one-way and two-way concrete solid slab by using ETABS software.

6.1 Conclusion

The conclusion drawn from the work done can be summarized as follows.

- Both composite slab and traditional concrete solid slab carried by the same reinforced concrete beam showed the same flexural behavior and had similar load carrying capacity in static test. Yet composite slab showed more total deflection than solid slab but with less crack width.

- In m-k value test all specimens, both long span and short span, failed under longitudinal shear stress with a ductile mode of failure. In comparison with other authors results the value of shear bond of the composite slab, which was made by the locally available material, is acceptable.
- The four different cases in slip capacity tests illustrate that no slip has been developed between the slabs and the beam as all of them has been casted together so the shear forces would be transferred by the concrete itself. Thus an advantage can be gained by using this system as no slip will be developed. However, all cases showed brittle behavior in accordance to Eurocode 4 evaluation. It should be mentioned that although slab reinforcement is only for shrinkage and temperature it played the main role in increasing the system load carrying capacity and providing it a ductile failure mode.
- The comparison among identical building frames with three different slabs indicated that the building with composite slab is lighter than the building with one-way solid slab by about 10% and with 50% less slab reinforcement, around 23% less concrete and by around 2.6 times faster construction. On the other hand, for the same building the composite slab building is lighter than the building with two-way solid slab by about 36% and with 67% less slab reinforcement, around 39% less concrete and by around 2.5 times faster construction.
- In brief the composite slab which consist of galvanized steel sheet with in-situ concrete can be applied easily on reinforced concrete beam under gravity loads.

6.2 Recommendation for Future Work

- More investigation should be done about this topic as there is a lack of information in the literature about this type of applications

- Special attention should be paid to the practical application of shuttering of the reinforced concrete beam as one of the timber beam will carry the composite slab as a result the wet concrete during casting.
- Type of diaphragm and the behavior of the system under seismic load should also be studied.
- The shrinkage and temperature reinforcement or the wire mesh in composite slab can be replaced by steel fiber.

REFERENCES

[1] Nie, J., Cai, C., & Wang, T. (2005). Stiffness and capacity of steel–concrete composite beams with profiled sheeting. *Engineering Structures*, *27*(7), 1074-1085.

[2] Nie, J., Fan, J., & Cai, C. (2008). Experimental study of partially shear-connected composite beams with profiled sheeting. *Engineering Structures*, *30*(1), 1-12.

[3] Xing, Y., Han, Q., Xu, J., Guo, Q., & Wang, Y. (2016). Experimental and numerical study on static behavior of elastic concrete-steel composite beams. *Journal of Constructional Steel Research*, *123*, 79-92.

[4] Ataei, A., Bradford, M. A., & Liu, X. (2016). Experimental study of composite beams having a precast geopolymer concrete slab and deconstructable bolted shear connectors. *Engineering Structures*, *114*, 1-13.

[5] Cifuentes, H., & Medina, F. (2013). Experimental study on shear bond behavior of composite slabs according to Eurocode 4. *Journal of Constructional Steel Research*, *82*, 99-110.

[6] Hossain, K., Alam, S., Anwar, M., & Julkarnine, K. (2016). High performance composite slabs with profiled steel deck and Engineered Cementitious

Composite – Strength and shear bond characteristics. *Construction and Building Materials*, *125*, 227-240.

[7] Lakshmikandhan, K. N., Sivakumar, P., Ravichandran, R., & Jayachandran, S. A. (2013). Investigations on Efficiently Interfaced Steel Concrete Composite Deck Slabs. *Journal of Structures*, *2013*, 1-10.

[8] Cifuentes, H., & Medina, F. (2013). Experimental study on shear bond behavior of composite slabs according to Eurocode 4. *Journal of Constructional Steel Research*, *82*, 99-110.

[9] Ali Shariati. (2012). Various types of shear connectors in composite structures: A review. *International Journal of the Physical Sciences*, *7*(22).

[10] An, L., & Cederwall, K. (1996). Push-out tests on studs in high strength and normal strength concrete. *Journal of Constructional Steel Research*, *36*(1), 15-29.

[11] Hirama, C., Ishikawa, T., & Hisagi, A. (2017). 08.21: Shear strength of headed stud push-out tests: Comprehensive literature review focusing on slab type, failure mode, and large-diameter headed stud. *ce/papers*, *1*(2-3), 2013-2022.

[12] Jayas, B. S., & Hosain, M. U. (1988). Behaviour of headed studs in composite beams: push-out tests. *Canadian Journal of Civil Engineering*, *15*(2), 240-253.

[13] Han, Q., Wang, Y., Xu, J., & Xing, Y. (2015). Static behavior of stud shear connectors in elastic concrete–steel composite beams. *Journal of Constructional Steel Research*, *113*, 115-126.

[14] Wang, J., Guo, J., Jia, L., Chen, S., & Dong, Y. (2017). Push-out tests of demountable headed stud shear connectors in steel-UHPC composite structures. *Composite Structures*, *170*, 69-79.

[15] Porter ML, Ekberg Jr CE. Investigation of cold-formed steel-deck reinforced concrete floor slabs. In: Yu W-W, editor. First specialty conference on cold-formed steel structures. Rolla: University of Missouri-Rolla; 1971. p. 179–85