REVIEW STUDY ON THE BOND SLIP BEHAVIOUR BETWEEN CORRUGATED STEEL SHEETAND CONCRETE

Abhinand R S[1], Harith Suraj D[2]
[1] *PG Structural Engineering Student , College of Engineering Trivandrum, Kerala , India*
[2] *Assistant Professor, Department of Civil Engineering , College of Engineering Trivandrum, Kerala , India*

Abstract— Composite Floor slab systems are being used in various structures due to its many advantages. There are mainly 3 modes of failure for composite steel form deck slab. In that bond slip failure is being discussed in this study. In CSRC composite slabs, the bond behavior between the corrugated steel plate and concrete is obtained from push-out and pull-out tests. The test setup and preparation of the sample is explained in the paper. Based on these small-scale tests a load slip behaviour curve can be obtained and the factors affecting the bond slip behaviour can also be understood. Interpretation of the load slip behaviour and factors influencing this bond strength of steel form deck and concrete are also explained.

. Keywords— Composite steel form deck slab, bond slip failure, corrugates steel plates, push- out and pull- out tests

I. INTRODUCTION

Composite construction in the context of construction industry refers to the use of two complimentary materials that is structural steel and reinforced concrete (As steel and concrete are, respectively, the most effective engineering materials for carrying tension and resisting compression) together in a component such a way that the resulting structure functions as a single unit compared to reinforced concrete construction and make the best use of the effective material properties of both steel and concrete. It is the main form of construction in the multistoried building sector. They offer significant advantages related to speed of construction and reduced overall construction depth. The past few decades have seen outstanding advances in the use of composite materials in structural applications. The aim is to achieve higher performance strength and stiffness, while minimizing the use of material than would have been the case had the two materials functioned separately. Today, the use of composite floor slab systems in construction is common practices.

ASCE defines it as "A composite slab system shown in figure 1 is one comprising of normal weight or lightweight structural concrete placed permanently over cold-formed steel deck in which the steel deck performs dual roles of acting as a form for the concrete during construction and as positive reinforcement for the slab during service", Amongst the numerous advantages of composite slabs over reinforced concrete slabs are lightweight and easy handling in erection of steel decks.

II. BEHAVIOUR OF CSRC SLAB

Composite slab behavior is a function of the interactions between the components of the slab. Two of the most important interactions that significantly affect the slab behavior are:

(i) The shear interaction at the interface of steel deck and concrete.
(ii) (ii) The interaction between the concrete, steel deck and end condition at supports.

III. MODES OF FAILURE OF CSRC SLAB

Composite slabs under bending can exhibit three major modes of failure as in fig .2:

- Flexure failure (Sagging moment) at section A
- Horizontal shear failure at section B
- Vertical shear failure at section C as shown in Fig 2.

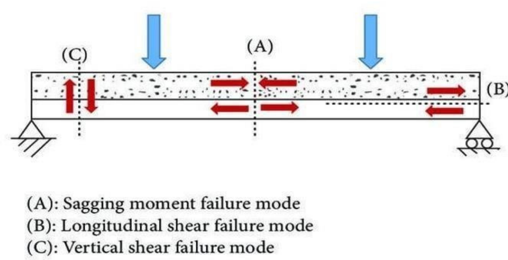

Fig.2: Modes of failure in composite slab (Johnson, 1994)

The characteristic of the vertical shear failure is that for this failure mode to be dominant, the slab has to be very short and thick with a high concentrated load near the supports. This is not common in construction practice, therefore, much research has not been done and the effect is usually ignored in design.

Horizontal shear failure commonly called shear bond failure is the common failure likely to occur for most composite slab systems subjected to vertical loads. This is characterized by the development of an approximate diagonal crack under or near one of the concentrated loads just before failure, followed by an observable end-slip between the steel deck and the concrete, as illustrated in Fig 3.

Thus, the strength and behavior of composite slabs which fail by horizontal shear depend on several major factors such as shear transfer devices, steel thickness and slab slenderness. The shear transfer devices are usually a combination of steel profile shape, indentations or embossments on the steel surface and end anchorages.

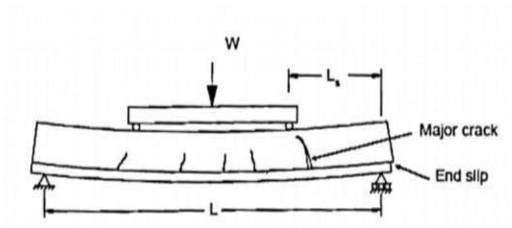

Fig.3: Horizontal Shear failure (Abdullah ,2004)

IV. Advantages

Composite slabs are commonly used (with composite beams & steel columns) in the commercial, industrial, leisure, health and residential building sectors due to the speed of construction and general structural economy that can be achieved. Although most commonly used on steel framed buildings, composite slabs may also be supported off masonry or concrete components.

Composite slab systems have been widely used in steel- framed structures. The system has proven to be very attractive to structural designers because of many advantages it has over conventional systems of reinforced concrete slabs. The main advantages of composite construction are:

- Durability: Steel deck has a successful long life of over 60 years, which is indicative of the products durability.
- Economy and Value: Value is determined by combining initial costs, life-cycle costs, and overall performance. They combine low cost with top performance.
- Speed of construction: The use of the decking as a working platform speeds up the construction process. Minimal reinforcement is required, and large areas of floor can be poured quickly. Floors can be concreted in rapid pace.
- Safe method of construction: The decking can provide a safe working platform and act as a safety canopy to protect workers below from falling objects.
- Saving in weight: Composite construction is considerably stiffer and stronger than many other floor systems, so the weight and size of the primary structure can be reduced.
- Saving in transport: Decking is light and is delivered in pre-cut lengths that are tightly packed into bundles. A smaller number of deliveries are required when compared to other forms of construction.
- Structural stability: The decking can act as an effective lateral restraint for the beams, provided that the decking fixings have been designed to carry the necessary loads and specified accordingly.
- Sustainability: Steel has the ability to be recycled repeatedly without losing its inherent properties. At least 94% of all steel construction products can be either re-used or recycled upon demolition of a building.
- Easy installation of services: Cable trays and pipes can be hung from hangers, thereby facilitating the installation of services such as electricity, telephone and information technology network cabling. These hangers also allow for convenient installation of false ceilings and ventilation equipment.
- Applications: Composite slabs have traditionally found their greatest application in steel framed office buildings, but they are also appropriate for the following types of building:
  - Parking lot of commercial buildings
  - Industrial buildings and warehouses
  - Hospitals
  - Cinemas
  - Housing

Since, composite slabs comprise of profiled steel decking as the permanent formwork to the underside of concrete slabs spanning between support beams, therefore, decking acts composite with the concrete under service loading. It also supports the loads applied to it before the concrete has gained adequate strength.

V. Shear Bond Strength

Strength of the interface between any two materials in carrying a load parallel to their longitudinal axes. Relation between the horizontal load and horizontal slip defines the shear-bond strength.

The shear-bond strength has three components, chemical adhesion, friction and mechanical interlock. The chemical adhesion component arises due to chemical bond action between the cement in the concrete and the surface of the steel sheeting. The friction component depends on the normal stress and the coefficient of friction once chemical adhesion has failed. In profiled composite structures, the mechanical interlock component depends on the embossments and the re-entrant (if present) portion's geometry. Mechanical interlock provides the shear connection required for the efficient structural combination between steel profile and concrete. The idea is to prevent slip and vertical separation at the steel-concrete interface and to achieve the composite action. Mechanical interlock is generally achieved by:

(i) Embossments projecting from the sides of the profiled steel ribs into the concrete, or indentations in the web or flange of the steel profile.
(ii) The re-entrant shape of the steel profile as in figure 4, which can lock the concrete into the steel profile.

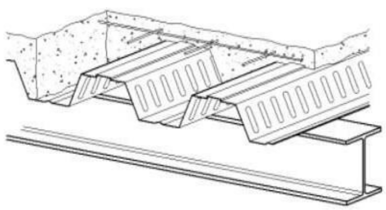

Fig.4: Reentrant steel sheet (Abdullah, 2004)

Various factors that affect bond strength are as follows:

1) Effect of concrete strength
2) Effect of concrete cover
3) Effect of embedded length
4) Effect of Recycled Aggregate Concrete (RAC)
5) Effect of Prestressed Concrete
6) Effect of diameter, length and number of studs and thickness of steel plate

VI. Types Of Shear Connectors

The use of shear connectors is another way of transferring shear forces between the steel profile and concrete, and limiting the longitudinal slip and preventing the uplift at the interface of the steel sheet and concrete. The shear connectors used in steel-concrete composite structures can be classified into four types: mechanical joint, friction bonding, adhesion, and finally adhesives each of which contains several methods. Among these four types, mechanical joints have been widely because high composite effect can be expected even with small contact area

The different types of mechanical shear connector that can be found in composite structures are as follows:

1. Headed Studs: The most commonly used type of shear connector is the head stud shown in figure 5. It resists horizontal shear and vertical uplift forces in composite steel-concrete structures. The studs are welded to the beam, normally through the deck sheet. This enables the concrete slab to act like a large top flange to the composite beam when the concrete has hardened and creates a stronger section to support the loadings applied to the finished slab. As a result of the high degree of automation in the workshop or on site, this type of connector is commonly used worldwide.

Fig.5: Headed Studs (Ali Shariati *et.al* ,2012)

2. Perfobond Ribs: This connector developed in Germany includes a welded steel plate, with a number of holes as shown in figure 6. The flow of concrete through the rib holes formed dowels that provide resistance in both the vertical and horizontal directions. It not only ensures the concrete steel bond, but also enables a better anchorage of the internal columns hogging moment has encouraged its adoption.

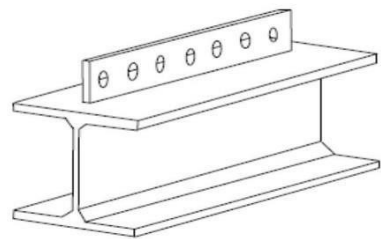

Fig.6: Perfobond Ribs (Ali Shariati *et.al* ,2012)

3. T-rib Connector: It is an alternative connector for headed studs, called the T-perfobond. It was created by adding a flange to the perfobond rib, which acts as a block. The need to combine the large strength of a block type connector with some ductility and uplift resistance arising from the holes at the perfobond connector web is lead to the development of this T-perfobond connector. As leftover rolled sections can be used to produce the T-rib connectors shown in figure 7, it can reduce cost and minimize welding work.

Fig.7: T-rib Connector (Ali Shariati *et.al* ,2012)

4. Oscillating Perfobond Strips: As compared to the headed studs and T-shape connectors, this type of connector has larger load capacity. However, due to the fast drop of the load capacity after the peak, the performance of this connector in the case of ordinary strength and normal weight concrete is rather disappointing. However, the absence of

such behavior when they are in use in lightweight concrete, concrete with fibres or high strength concrete allows the oscillating perfobond strips connectors shown in figure 8 to perform well.

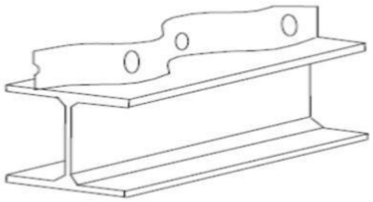

Fig.8: Oscillating Perfobond Strip (Ali Shariati *et.al* ,2012)

5. Waveform Strips: The objective of the curved form is to improve the transfer of force between the steel and the surrounding concrete when compared to a straight connector. It would be more difficult to weld using conventional automated welding equipment shown in Figure 9.

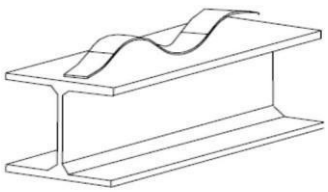

Fig.9: Waveform Strips (Ali Shariati *et.al* ,2012)

6. T-Connectors: This connector is a section of a standard T-section welded to the H or I section with two fillet welds. Therefore, a T section, which has a larger cross section than a single strip, and by its shape prevents vertical separation between the steel and the concrete seems to be a good alternative. When used in concrete with fibres, lightweight concrete or a higher strength concrete, there is a notable increase in the load capacity and ductility of this type of connector.

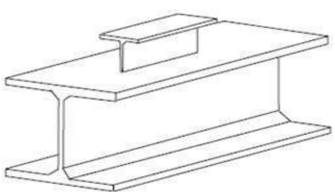

Fig.10: T-Connectors (Ali Shariati *et.al* ,2012)

7. Channel Connector: Channel connectors shown in figure 11 might not need inspection procedures, such as bending test of headed studs, due to the highly reliable conventional welding system used in the welding of these connectors. The load carrying capacity of a channel shear connector is higher than that of a stud shear connector. This enables replacement of a large number of headed studs with a few channel connectors.

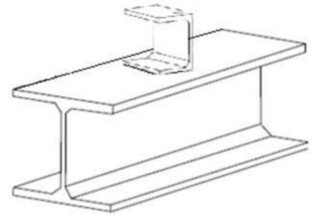

Fig.11: Channel connector (Ali Shariati *et.al* ,2012)

8. Pyramidal Shear Connectors: It is a type of welded shear connector, sufficient bending strength and flexural rigidity for loads during and after construction is expected from a steel plate concrete composite slab with pyramidal shear connectors shown in figure 12. A thin steel plate composite slab, which is composed of a bottom steel deck and concrete through pyramidal shear connectors could also be one of them. The fatigue strength is reduced when such a thin steel plate composite slab is applied to a bridge deck subjected to traffic loads.

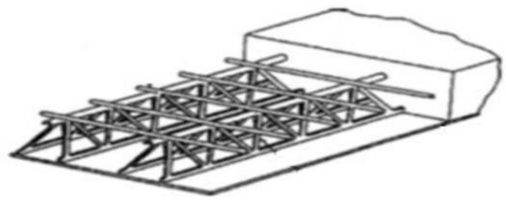

Fig.12: Pyramidal Shear Connectors (Ali Shariati *et.al,* 2012)

9. Rectangular shaped collar connectors: This connection device consists of a collar composed of two or more parts, astride the timber beam, bolted together at adjacent wings as in figure 13. At the collar-beam interface, a rubber layer is interposed. The superior wings of the collar or a steel stud, purposely welded to the collar in the upper part, which are immersed in the concrete cast, guarantees the slipping action transmission.

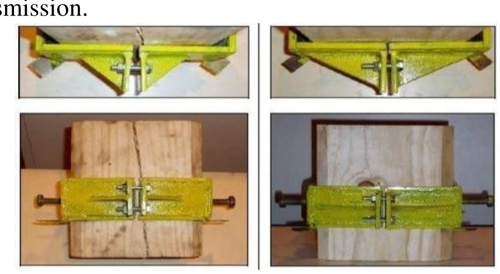

Fig.13: Rectangular shaped collar connectors (Ali Shariati *et.al,* 2012)

VII. TESTS FOR BOND SLIP

The efficiency of the composite action for steel sheeting is currently thought to be reliably obtained only from test information. The methods of measuring shear-bond resistance may be by full-scale tests of concrete slabs or full-scale tests in combination with small-scale model tests. The most widely used small scale tests which are recommended by Eurocode 4 are:

(i) Pull-out test: similar to that used for reinforcing bars in conventional reinforced concrete, where a tensile load is applied to one end of the reinforcing bar. 2. Push-off test: similar to that used for composite structures as composite beams and composite slabs, where a compressive force is applied to the concrete.

Compared to the push-out setup, the pull-out test setup showed an overestimation of the bond stress due to the higher deformation in the ribs and soffit of the steel deck. The pushout test method has been widely used since it is simple and easy to operate.

(A) Preparation of specimens

Material properties is studied by conducting compressive test and tensile test on concrete and steel used for sheeting respectively. The specimens are designed such that the width includes two ribs which allows the application of the push load in the middle pan (above soffit and between two ribs), as shown in Fig. 8. Based on the two-ribbed deck width, the bond length is fixed such as to achieve the adequate specimen size so that sufficient bond strength can be measured while preventing the specimen from overturning by the push load. Height of the specimens is fixed such that enough cover is available. The steel deck is fixed to a base plate with bolts. The steel deck surface is well cleaned just before casting the concrete. Concrete is prepared in the laboratory and specimens are casted. The specimens are compacted manually, covered and left in the formwork for 24 hours, then demoulded, and then they are placed in a curing tank at a constant temperature of 23 ◦C and humidity of 55% until the test day.

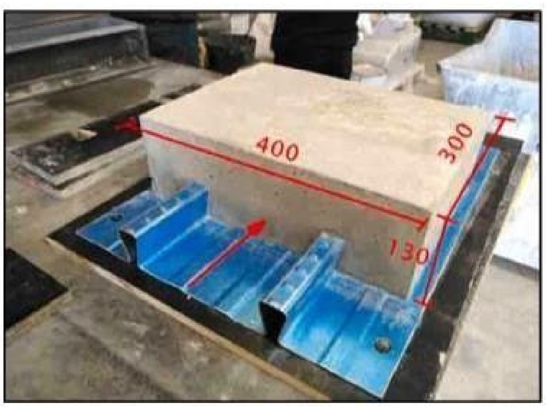

Fig.8: Details of the specimen (units in mm) (Julie E. Mills et.al, 2021)

(B) Test setup

1) Aim:

a) to shear off the concrete block from the steel deck
b) to measure the longitudinal shear bond that exists at the interface between the concrete and the profiled steel.

2) PROCEDURE

i. The load applied to the pushing plate is transferred to the concrete-steel interface, as shown in Fig. 9.
ii. At the interface, this load is resisted by the shear devices (corrugation of steel sheet and embossments) which transfers the shear bond to the steel sheet bolted down to the base plate.
iii. After the test, the concrete block is separated from the steel deck to investigate the interface.

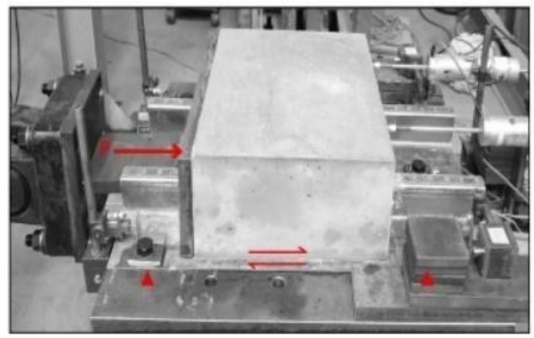

Fig.9: Transfer of shear in push off test (Julie E. Mills et.al, 2021)

iv. The CSRC specimens are loaded on a pressure testing machine, and the test setup is shown in Figure 10.
v. The side adjacent to the loading device (the position of the actuator head end) called as the loading end, the other side of the CSRC specimen is called as the free end.
vi. The loading rate is kept 0.3 mm/min post -peak performance recorded easily
vii. The loading end - slippage occurs first occurs, the adhesion force transferred from the loading end to the free end.
viii. CSRC specimens is considered damaged-corrugated steel plate is pushed out by >15 mm.

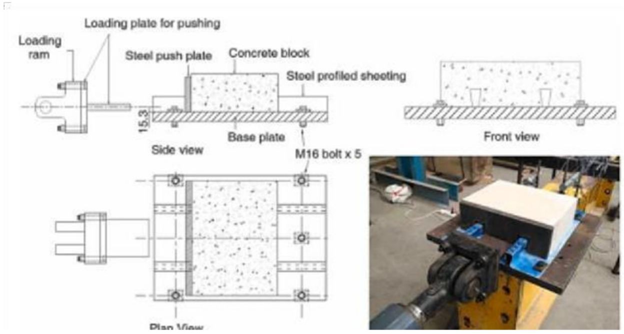

Fig.10: Test set up (Julie E. Mills et.al, 2021)

ix. The measurement of the push-out test can be divided into:
   i. Slippage measurement at the loading end and free end- Linear Variable Differential Transformers (LVDTs)
   ii. Strain measurement of the corrugated steel plate-Strain gauges distributed at equal intervals at the loading end

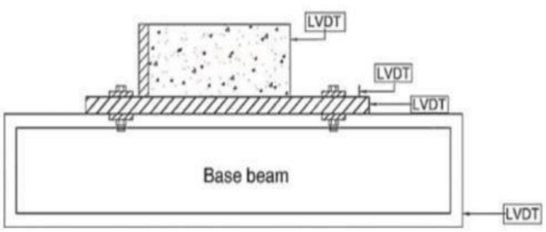

Fig.11: Position of LVDT sensors (Julie E. Mills et.al, 2021)

Fig.11: Strain gauge positions (Julie E. Mills et.al, 2021)

j) At the initial stage -no relative slip is generated inside.
k) As the load continues to increase slippage at the load end increases slowly cracks at the end face develop rapidly.
l) Crack extends from the loading end to the free end, and split cracks appear on the sides of the specimen.
m) The slip at the load increases very slowly when the load increases near the ultimate load.
n) The load rapidly drops after the ultimate load is reached.
o) At this time, the slippage at the load side develops rapidly and the free end begins to slip.
p) The load decreases slowly and finally stabilize with the rapid development of slip at the load end and free end.
q) Cracks develop more quickly and the surface cracks of the specimens are connected to each other to form long cracks. The longitudinal splitting crack width can reach 2–3 mm.
r) Two critical load levels can be used to define the behavior:
   i. Average load at which slip is

first recorded, after the chemical bond is broken down.
   ii. Maximum load recorded before slab fails

VIII. RESULTS AND DISCUSSIONS

Push and pull-out test are conducted and the values thus obtained that is the load and corresponding slip values obtained is noted and by using that a load slip curve is plotted. With the aid of this graph the bond slip behavior of corrugated steel reinforced slab can be analyzed.

At present, research on the bond-slip behavior of CSRC composite structures mainly focused on CSRC composite slabs, while there are few studies on the bond-slip behavior of CSRC composite shear walls and columns. By deepening the understanding of the bond slip behavior of the CSRC composite structure, the connection performance between the corrugated steel plate and concrete can be effectively improved. Moreover, it is of great significance and practical value to fill in the gaps in the relevant regulations and to promote the engineering application of CSRC composite shear walls and columns.

LOAD SLIP BEHAVIOUR

The characteristic P-S curve of the loading end of the CSRC specimens as per the studies of Jiangliang Song et.al, (2021) is shown in Fig 20. P-S curve can be divided into the following three stages: the load ascending section OB, the load descending section BD and the residual load section DE. Point O is the origin of the coordinate; point A is the initial slip point of the specimens, and the corresponding load and slip are Ps and Ss, respectively, point B is the peak point, where the correspondingload and slip are Pu and Su, point C is the sudden drop point, where the corresponding load and slip are Pc and Sc, and point D is the residual point, where the corresponding load and slip arePr and Sr, respectively. The bond-slip mechanism between the interface of the corrugated steel plate and concrete can be summarized as follows:

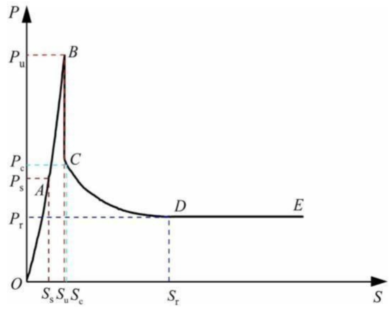

Fig.12: Typical load slip behavior graph (Jiangliang Song et.al ,2021)

1) No-slip phase (OA segment): During the initial loading phase, no significant slippage occurs at the loading end and the free end. Chemical adhesion, frictional force and mechanical bonding plays a major role.

2) Destruction phase (A-B segment): The slope of section AB is quite different from that of section OA because the slippage between the corrugated steel plate and concrete gradually increased when the corrugated steel plate is pushed out. Then, cracks are gradually formed when the load is close to the ultimate load, the slip at loading side develops quickly between the corrugated steel plate and concrete until the inside concrete is crushed, which results in the loss of the chemical bonding. Hence, the chemical bonding force of CSRC specimens is gradually lost during the push-out process.

3) Falling phase (B-C segment): After the load reaches the peak, the loading and free ends are carried out at the same time rapidly, and the cracks of the specimen are fully developed
4) Load residual phase (C-D segment): In section CD, the interfacial bond force of the CSRC specimens is mainly supported by the mechanical bond force and the friction force. As the corrugated steel plate is gradually pushed out, the slipping region spread to the entire interface along the embedment length hence, the interfacial chemical bonding force between the corrugated steel plate and concrete is continuously lost.
5) Residual load section DE: when the corrugatedsteel plate of most CSRC specimens is pushed out by approximately 5 mm, the load tends to be gentle.The loss of interfacial chemical bonding force between the corrugated steel plate and concrete causes the concrete pieces inside the specimen to be continuously rubbed on the defective surface ofthe corrugated steel plate, which causes theinterface surface to be smooth and the mechanical bond force to be reduced. Finally, the adhesion force between the corrugated steel plate and concrete is only supported by the friction force. Since the interfacial friction coefficient between the corrugated steel plate and concrete is approximately constant, the residual load of the CSRC specimens tends to be a horizontal straight line.

Chemical bond is derived from the maximum load at which the chemical bond failed by dividing the load by the entire contact area between the sheeting and the concrete. The residual stress is considered the minimum value after failure of the chemical bond and before the effect of mechanical bond. The average mechanical bond stress is found by dividing the average load between the residual bond and load at 5 mm slip by the entire contact area between the sheeting and the concrete.

IX. Interpretation By The Author

Bond slip failure in Corrugated Steel Reinforced Concrete (CSRC) Slab is a major concern in composite construction. This seminar paper focuses on the bond slip behavior of CSRC Slab. Many useful findings were made from the works of different researchers who investigated the effect of bond slip behaviour under various conditions. Some of these findings were;

a. Shear connectors play an important factor in increasing the bond strength between corrugated steel sheet and concrete interface

b. Despite being commonly used to transfer longitudinal shear forces across the steel concrete interface, the headed stud shear connectors have some disadvantages and difficulties to be used in composite slab lead to the inventions of other shear connectors

c. The materials and method used in concrete greatly influence the bond strength. The recycled aggregate used showed a positive influence in bond strength. While the use of prestressed concrete showed a negative influence

d. Various factors such as the concrete cover, concrete strength, embedment length, concrete cover thickness etc. have a significant role in the bond strength.

X. Conclusion

Composite slabs with profiled steel sheets (acting as permanent formwork during construction and as tensile reinforcement during service) have received considerable attention and has been an important area of research for over a decade now, mostly because of the positive effect it has in the construction industry due to various reasons like easy to install, lightweight, and economical etc. The more ductile properties of CRC are expected to provide improved bond performance within the composite slabs since the composite action between profiled steel deck and concrete is affected by the compatibility of deformation properties between the two materials. Compared to the failure in flexural and vertical shear which are common for flexure members, the steel deck reinforced composite slabs are more prone to fail in longitudinal shear bond.

In recent years, many researchers have tried their best to understand the influencing parameters of the bond-slip behavior in corrugated steel reinforced concrete slabs. It is generally recognized that the bond-slip behavior of steel section encased in concrete is affected by various factors such as the concrete cover, concrete strength, embedment length, concrete cover thickness etc. The choice of replacement materials to be used in the concrete such as using recycled aggregate concrete and using of prestressed concrete also greatly affects its bond slip properties. In general, it can be concluded that the bond which must be achieved between the profiled steel sheet and the concrete is very crucial for the composite action of post-tensioned composite slabs.

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