JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

COGNITIVE REVIEW OF STRUCTURAL PERFORMANCE OF PROFILED STEEL SHEET CONCRETE SLAB

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Abstract: Many studies on the structural performance of composite slabs with conventional concrete have been conducted as, structural designers have found this system to be particularly appealing due to the many benefits it provides over traditional systems of reinforced concrete slabs. Correspondingly significant research & developments have been made in this non- conventional technique of slab laying. Such innovations pertaining to the components of composite slab and its consecutive influence on structural performance have been reviewed and presented through this study.

Index Terms **- Composite Slab, Innovation, Structural Performance, Review.**

I. INTRODUCTION

A slab with an in-situ concrete topping and a profiled steel deck is known as a composite concrete slab. During construction and throughout its useful life, the steel deck serves as permanent formwork and reinforcement respectively. (1, 4, 6) Since 1980, the use of these composite slabs in structures has grown significantly. The total depth may range from 100 to 170 mm. The deck/profiled steel sheet's thickness can range from 0.7 to 1.2 or more, and it is often galvanized to boost durability. (2) Quick construction and lighter floor building are outcomes of the composite deck flooring. Also, it serves as a suitable ceiling surface and an easy-to-use ducting for routing. (3)

A structural element that is made of two or more different materials and is linked together to function as a single unit is known as a composite design. Steel and concrete are the most significant and common elements to combine in construction. (figure 1 & 2). These two materials perform well in tandem and accentuate one another. Almost the same thermal expansion occurs in both. They have a good blend of strengths with the concrete effective in compression and the steel in tension.

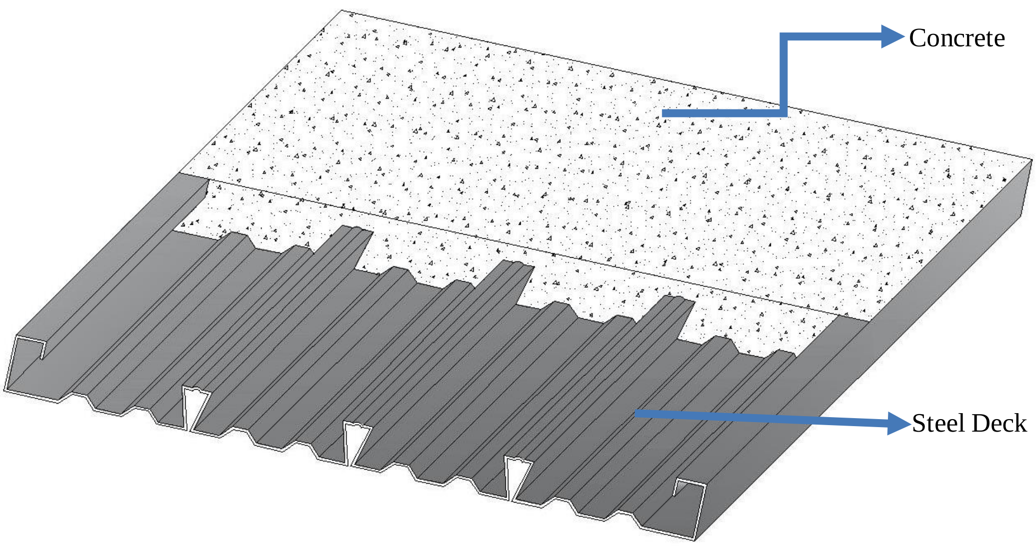

figure 1: isometric view of composite slab

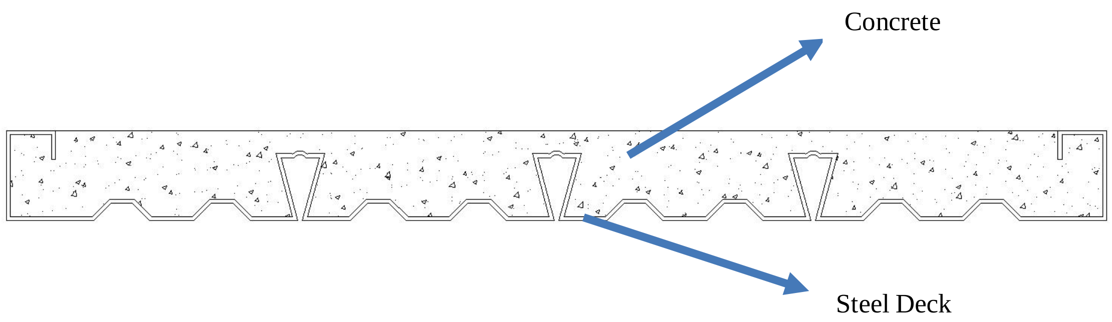

figure 2: sectional view of composite slab

During its usable life, the metal sheet serves as both the formwork for pouring concrete and the principal tension reinforcement. Most often adopted as tension reinforcement are Trapezoidal profile with web indentations and Dovetail profile (Re-entrant). The composite action between steel beams and concrete is developed using mechanical or shear connectors. The sectional and Isometric view of steel decks is visible in figure 3 & 4. The "shear connection" is a connection that is primarily designed to resist longitudinal shear.

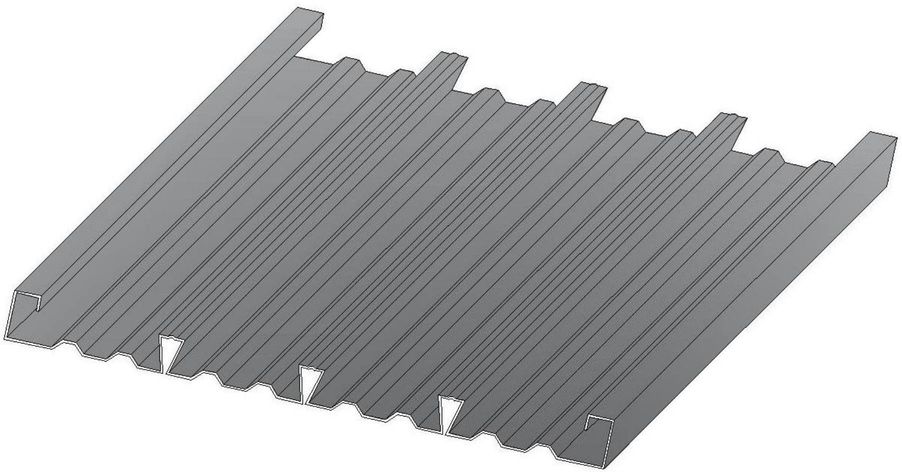

figure 3: isometric view of steel deck

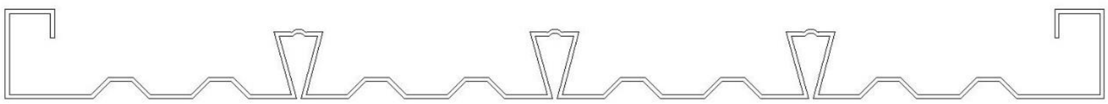

figure 4: sectional view of steel deck

Mechanism of composite Slab: Many research studies have been conducted in recent decades to better understand the complicated phenomena of the composite deck slab's interface shear behavior. The interface bond between the steel and concrete determines the strength of the composite slab.

Contrary to reinforced concrete, Cifuentes and Medina established that the compatibility of the deformation characteristics of the two materials influences the composite action between profiled steel deck and concrete. (4) There are three elements that make up the longitudinal shear connection between the steel deck and the concrete: chemical adhesion, physical/friction component, and mechanical interlock. (4,5) The shear transfer devices, for example, are a parameter that affects the bond strength (embossments, corrugation of ribs, and end anchorages). (5,6,7).

The longitudinal shear transfer mechanism at the juncture of the steel and concrete influences the strength of the composite deck slab predominantly. The composite deck slab prematurely fails due to the poor binding strength created by the cement paste. A shear transferring device that employs mechanical interlock via indentations, embossments, or attaching studs successfully eliminates this weakness. Between steel and concrete, the mechanical interlocking mechanism in the deck profile provides rigidity (strength) to vertical separation and horizontal slippage. (3) Using the compressive strength of concrete slabs along with steel beams to increase the strength and stiffness of the steel section is the advantage of steel-concrete composite construction.

Codal provisions: A great deal of study has been done on composite slabs, and as a result, the foundation for successful composite slab design standards has been laid. In the present American (ASCE 1992), British (BS 5950 1994), European (Eurocode 4 – 1994) and Australian (AS 2327:2017) there are numerous standards for the design of composite slabs. The partial shear connection (PSC) method and the shear bond method, often known as the m-k approach, are two commonly used techniques for designing composite slabs.

II. METHODOLOGY

Initially the design criteria and calculations of profiled sheet-concrete slabs were studied. The cognizance of relevant literature of the aforesaid topic were made. Figures showcasing the components contributing/ affecting the structural performance of composite slab were prepared using AutoCAD as displayed in **figure 1,2,3 & 4**. The cognitive review of the study has been prepared.

III. REVIEW OF LITERATURE

P. A. Sarode and Dr. S. R. Parekar's (8) research on "Composite slab with profiled steel deck" examined literature pertaining to the behaviour of composite slabs with profiled steel decking and requirements found in the Eurocode and British code. The researcher came to the conclusion that the provisions of the Codal are based on experimental studies and the finite element analysis of composite deck slab with nonlinear connections between the profile deck, shear connectors, and concrete. Recent research demonstrated that the profiled deck system's ultimate load bearing capability and first concrete cracking load are larger than those of the RC deck slab. European codes allow for the design of composite slabs using either the M-K technique or a partial interaction approach, however British standards exclusively use the M-K method.

The design of a composite slab utilizing Indian Standard and Eurocode is described in depth in the paper "Design of composite deck slab" by Kamal B., Alamelu G., and Abinay D. (9) The results of using composites and their advantages are researched. The durability of the part will enhance with the use of composite. Construction of prefabricated buildings makes use of composite materials. With the use of an experimental prototype investigation, the composite slab's effectiveness and durability may be determined.

In the article "Structural strength and behaviour of profile steel sheet-concrete composite slab," S. M. Zahurul Islam, Shah Alam, and Bulbul Ahmed (10), introduced the three varieties of steel profile concrete composite slabs, which comprise studs, minimal reinforcement, and without reinforcement. According to the results of the experimental inquiry, the ultimate capacity of a composite slab utilising reinforcement and stud was enhanced by two and three times, respectively, compared to the reference test of a slab without reinforcement. Before the shear-bond breakdown, the load deflection curves for the concrete composite slab with studs were more linear than those for the slab with reinforcement. De-bonding, cracking at the sheet-concrete interface, and load-deflection curves for composite slabs all became non-linear as the load rose. The test findings and comparisons of the experimental and analytical results were in good agreement, and the predictions of the behaviour and load bearing capability of composite slabs were accurate.

The use of profiled steel sheeting in floor construction was the subject of a research by H.D. Wright, H.R. Evans, and P.W. Harding (11). Every component of the system's behaviour has been examined by the research. The outcomes of more than 200 experiments have been compared with existing design methodologies. A frequent structural component in composite structures is the profiled steel sheet-concrete composite slab; the mechanical characteristics at high temperatures and the thermal characteristics of the steel-concrete structure serve as the foundation for studying structural response. When it comes to exerting the composite effect of steel and concrete in composite slabs during a fire, the bonding qualities of profiled steel sheet and concrete are crucial. The most common flooring method in Britain is quickly evolving to include profiled steel sheeting as permanent formwork, tensile reinforcement for an in-situ concrete slab, and through deck welded shear studs to produce composite beam action.

With the primary goal of determining the vibration characteristics of profile deck sheet for various forms of profile as composite slab system, Jagadeesan R., Preetha V., Vignesh P. S., and Senthilkumar V. (12) conducted the study "Impact of profile deck sheet in composite slab system." Based on natural frequencies and mode shape, a comparison of various shapes has been done to assess the dependability of profiled deck sheets in composite slabs. For rectangular and trapezoidal profiles, the differences in frequency were comparatively minor, although the stiffness of flat plates is low in comparison to other examples. Due to an increase in plate stiffness, the variance of ten mode forms and their frequency values differed significantly for flat plates and other shaped plates. The distorted shape of different profiled decks at a given frequency reveals the deck sheet's mode of vibration. Deck sheet's primary influencing factor is identified by the vibration mode form. The failure pattern and delimitation behaviour of the deck sheet with composite slab arrangement are reflected in the vibration mode shape.

The vibration performance of the PSSDB floor panel was examined by Ehasan Ahmed and Wan Hamidon Wan Badaruzzaman (13), in their work "Vibration performance of profiled steel sheet dry board composite floor panel." The fundamental frequency was the primary consideration, and the effects of various board types, board thickness, and connection spacing on fundamental frequencies were assessed. The fundamental frequency of every panel taken into consideration in this study was determined to be far above 8 Hz, therefore this sort of composite floor panel will be vibration-comfortable for building occupants.

In their paper "Investigations on effectively interfaced steel concrete composite deck slabs," authors K. N. Lakshmikandhan, P. Sivakumar, R. Ravichandran, and S. Arul Jayachandran (3) looked into a better, more straightforward interface mechanism. Experimental research was done on three different mechanical connecting techniques. The three shear connection designs displayed complete interaction and little slide. As compared to composite slabs without mechanical shear connections, the strength and stiffness of the latter were greater by around a factor of 1.5. The deck webs are integrated into the scheme 2 and scheme 3 shear connection mechanisms, which increase the deck's strength and stiffness and lower the cost of formwork and supports.

Profiled steel-concrete composite slabs, which are made of steel and concrete, are typically used to create bridge decks. Slip occurs at the point where concrete and steel meet, giving the composite slab its distinctive mechanical and fatigue qualities. Qingfei Gao, Ziliang Dong, Kemeng Cui, Chenguang Liu, and Yang Liu (2020) (14) conducted a study titled "Fatigue performance of profiled steel sheeting-concrete bridge decks subjected to vehicular loads" to look into the mechanical and fatigue performance of profiled steel sheeting-concrete bridge decks subjected to vehicular loads. The deformation and internal force components of composite plates were theoretically derived, and a new approach was developed for computing the deflection of profiled steel sheeting-concrete composite slabs based on a discontinuous stiffness. This method's mid span deflection and end-slip values were nearly identical to the experimental results. This study explored the fatigue design approach of the composite slab with a focus on the fatigue performance of the bridge deck and gives fatigue-check calculations for the Khartoum Al-Halfaia bridge across the Nile. The composite slab bridge's parameters were examined. The impacts of the profiled steel plate's section shape, strength grade, and thickness on fatigue performance were evaluated, and corresponding improvement strategies were considered. It was discovered that the fatigue performance of the composite slab is mostly unaffected by the concrete strength grade, however the thickness and section geometry have a considerable impact on the shear-stress amplitude of the plate end interface.

Yiming Liu, Qinghua Zhang, Yi Bao, and Yizhi Bu completed the work "Fatigue behaviour of orthotropic composite deck integrating steel and designed cementitious composite." in 2020. (15) To explore the fatigue resistance and failure process and to verify a finite element model that was used to clarify the impact of ECC on the fatigue performance, two full-scale composite decks were tested. Using models and experiments, this study suggests a composite deck with broad U-ribs and engineered cementitious composite (ECC) to increase fatigue resistance. According to the test findings, the composite deck exhibited adequate fatigue resistance, and the ECC overlay reduced the stress range at the rib to deck by 90%. One intriguing observation is that the suggested deck has a strong resilience to fatigue even after the deck structure has been damaged.

In order to be used in practise, this research offers a case study on the application of CRC in large-scale composite slabs reinforced by profiled steel deck. In a 2020 case study conducted in Australia Ou Yi, Julie E. Mills, Yan Zhuge, Xing Ma, Rebecca J. Gravina, and Osama Youssef completed a study titled "Structural Performance of Composite Slabs with Low Strength CRC Delivered by Concrete Truck" (16). This case study examined the effects of truck-delivered CRC that was poured over large composite slabs. The slabs were tested under a 4-point bending stress and reinforced with 0.75 mm thick BONDECK profiled steel sheet. The findings revealed that 30% loss in concrete compressive strength did not influence the load bearing capacity of composite slabs under bending, and slabs in 66% reduction in concrete strength reached 75% of the flexural performance of that in conventional concrete composite slabs. This shows that low-strength CRC may replace high-strength CRC in composite slabs and still achieve good flexural performance, proving that the flexural behaviour of composite slabs is not only dependent on concrete compressive strength.

Flexural characteristics of innovative cold-formed thin-walled steel and concrete composite slabs were the subject of research by Wentao Qiao, Xiaoshuo Yan, Renjie Zhu, Fuyu Wang, and Dong Wang (17). The specimens are examined with regard to their flexural capacity, ductility ratio, concrete strain, reinforcement strain, and C-section strain in order to assess the bending performance and failure mechanism of the composite slab. Findings reveal that despite having a satisfactory bearing capacity and ductility in the test, the composite slab breaks in a typical section of flexure. According to the assumption of a flat section, the strain in the concrete in the slabs is distributed linearly throughout the section height. The three-hole slab's mechanical performance is superior to the two-hole slabs. The numerical findings of flexural capacity are compared to the test results using finite element simulations; the comparison shows that they are in good agreement, which paves the way for the ensuing parametric analysis.

Building rules state that composite slabs must adhere to fire safety standards. This sort of element's fire resistance is often assessed using common fire tests. Paulo G. Piloto, Lucas M. S. Prates, Carlos Balsa, and Ronaldo Rigobello (18) carried out one such study titled "Fire resistance of composite slabs with steel deck: Experimental analysis and numerical modelling." The criteria for stability (R), integrity (E), and insulation (I) were applied to two samples as they were being assessed. Matlab PDE toolbox was used for the numerical modelling of the thermal effects of typical fire exposure. The outcomes were contrasted with those of the Eurocode-proposed streamlined procedure, which appears to be undesirable. Based on the straightforward calculation approach, the numerical simulation forecasts lesser fire resistance (I) in comparison to real norms. Because it produces a critical time value that is significantly larger than the one obtained with the numerical simulation, the fire resistance achieved using the straightforward calculation approach suggested in the Eurocode appears to be undesirable. By conducting practical testing in accordance with the criteria outlined in this study, experimental data are crucial for validating the numerical results.

Lamont et al. (19) conducted an examination of the Cardington building's composite slabs' heat transmission in 2001. Four experiments were conducted on various building levels. The temperatures through the slab were calculated using the adaptive heat transfer model. For the majority of the tests, the constructed model delivered good results.

Six slabs, including three reinforced concrete flat slabs and three composite steel-concrete slabs, were tested at the BRANZ fire resistance furnace in 2002 by Lim et al. (20) In order to determine their impact on limiting fracture widths to maintain integrity, the three flat slabs were reinforced with varied amounts of steel. The slabs had a live load of 3.0 kPa and underwent a three-hour bottom-up ISO 834 fire heating process. The slabs held up for the entirety of the testing without giving way. The tested slabs' structural fire resistance was more than expected based on code requirements.

Guo-Qiang Li et al. (21), in a more recent study in 2017, conducted four tests on composite slabs with steel decking that were fire-rated for 90 minutes and came to the conclusion that the Eurocode 4 design calculations are conservative and could be applied to other geometries outside of the predetermined parameters.

In the year 2014, Manjunath T. N. and B.S. Sureshchandra (22), as part of their "Experimental research on concrete slab with profiled steel decking," investigated the behaviour of composite slabs. The major goal was to analyse the behaviour of design mix and no fines concrete under composite action and to examine the behaviour of composite slab in flexure test in order to ascertain the impact of bond strength between chemical bond and mechanical bond by end slip test. This study found that using contoured deck sheet reduced concrete volume by 25%. Using chemical bond, sheets without embossments had a 14% higher maximum load bearing capacity than sheets with embossments. According to IS: 456-2000, the slab's deflection was within the allowed limit (1/350). No fines concrete (1:8 proportions) lowers 34% of cement, 100% of fine particles, and 9% of total aggregates by mass per cubic metre of concrete as compared to design mix concrete. Employing no fines Concrete decreases the slab’s self-weight by 21%. Design mixes for concrete slabs with and without embossment have almost identical flexural behaviour. Across the shear span, the longitudinal shear stress is not distributed evenly. The initial fracture and the beginning of the end slide were signs that the partial composite activity between the concrete and the steel had begun after the chemical bonding had been lost.

Xiao-Xiang He, Guo-Chang Li, and Zhi-Jian Yang (23) conducted an experimental investigation on the performance and failure behaviour of composite slabs with various spans, publishing their findings in "Experimental Study of the Bearing Capacity of Long-Span Profiled Steel Sheet-Concrete Composite Slabs." Two alternative cross-sectional geometries of a total of 26 profiled steel sheet concrete composite slab specimens were examined. In order to provide test data and theoretical guidance for the design and implementation of long-span composite slabs, variables including the depth of the composite slab, the arrangement of the anchoring studs, and extra reinforcement were examined. In contrast to extra reinforcement and thick profiled steel sheets, the test results showed that end anchoring may greatly improve the mechanical performance and ultimate bearing capacity of composite slabs. The findings also demonstrated that dovetail-profiled composite slabs had a greater load bearing capability than trapezoidal-profiled composite slabs in long span flooring systems.

To evaluate the shear bond strength under bending test in compliance with Eurocode 4, Namdeo Hedaoo, Laxmikant Gupta, and Narayanrao Ronghe (24), conducted an experimental test in "Design of Composite Slabs with Profiled Steel Decking: A Comparison between Experimental and Analytical Studies.". Analytically, the partial shear connection (PSC) technique and the m-k method are used to analyse and compare the longitudinal shear bond strength between the concrete and steel deck. The load-carrying capacity of composite slabs was studied experimentally and analytically, and the comparison of the findings showed that these values agreed to a sufficient degree. The longitudinal shear stress of the slab as a result of the loads calculated using the m-k approach is somewhat greater in comparison to the PSC method as the shear span length increases. It follows that the m-k approach has more longitudinal shear strength than the PSC method.

Experimental research was done by José M. Calixto, Armando C. Lavall, Cristina B. Melo, Roberval J. Pimenta, and Rodrigo C. Monteiro (25) on the "Behavior and Strength of Composite Slabs with Ribbed Decking." The behaviour and strength of full-scale, single-span composite slabs with ribbed decking are shown in this study. Different aspects were studied, including different steel deck thickness, total slab height, as well as shear span length. Also, the impact of connectors (stud bolt type) on the end anchoring was examined. The test findings clearly show that composite slabs constructed with stud bolt connections function better. In this investigation, when compared to the same specimens produced with ribbed decking alone, the slabs constructed with plain sheeting and stud bolts always achieved a greater ultimate load. The friction at the interface of the concrete decking over the supports and the resistance of the mechanical interlocking are not clearly separated in the present design formulae. Each resistance mechanism contributes differently to the performance of the ribbed decking, depending on the placement and design of the embossments (ASCE type II decks, for example). As a result, a method that explicitly considers the impacts of friction and mechanical interlocking independently is described. The findings of the current tests and those from other research are contrasted with the suggested technique. These evaluations reveal a strong link.

With the primary goal of determining whether a dense lightweight woodchips concrete meets the minimum requirements for strength in a composite with steel profiled sheets with undercut profiles, researchers Daniele Waldmann, Andreas May, and Vishojit Bahadur Thapa (26), conducted research under the title "Influence of the sheet profile design on the composite action of slabs made of lightweight woodchip concrete." The study offers extremely encouraging results and supports the advantages of composite constructions comprised of lightweight woodchip concrete and profiled steel sheets for use in the building and construction industries. Lightweight woodchip concrete was used in place of regular concrete, which resulted in a decrease in dead loads of up to 50% but a loss in load bearing capability of roughly 20%. The profiled steel sheeting raises the load capacity of the composite by four times while increasing the self-weight of the lightweight woodchip concrete by 7%. The final load increase is substantially influenced by the profiled steel sheet's thickness, and shear stress from lightweight woodchip concrete might pass to the profiled sheet.

In "Analytical Research on Concrete Slabs with Decking Profiled Steel Sheet," by Tarek Ali, Samesh Yehia, and Mohamed Ei-Didamouny (27), the structural behaviour of concrete slabs with decking steel sheet was examined for new constructions and conservation of existing buildings. Shear connectors are used to promote maximum deflection and ductility, which strengthens the connection between corrugated sheet and concrete. The spear span has a significant impact on how the profiled concrete slab behaves. The usage of reinforcing steel mesh enhances ductility and maximum ultimate load. By using contoured deck sheets, concrete volume is reduced by 20%. This study also demonstrated the effectiveness of using a nonlinear finite element approach based on sophisticated 3D models as a strong and reasonably priced tool to mimic the real behaviour of reinforced concrete slabs with profile steel sheet under challenging conditions.

In their study article "Fire resistant design of steel structure," B. Santhiya and Glshan Taj M. N. A. (28), explored the design guidelines and codes needed for fire resistant design of steel structures according to Eurocode 3. Researchers came to the conclusion that the kind and degree of fire protection, as well as the heating up of the structural element (such as pure steel or composite steel/concrete). The fire resistance criteria used by European standards, as well as the material attributes, design approaches, design methodologies, and design parameters, were provided.

Strength and shear bond properties of high-performance composite slabs with profiled steel deck and designed cementitious composite, by K.M.A. Hussain, S. Alam, M.S. Anwar, and K.M.Y. (29) A novel high performance composite flooring system using innovative, green, and cost-effective Engineered Cementitious Composites was developed and its performance evaluated by Julkarnine (ECCs). To assess the structural performance of such a flooring system during the building and service stages, experimental investigations in accordance with existing Standard Specifications and code-based theoretical investigations were carried out. Based on load-displacement response, shear load resistance, failure modes, strain development in concrete and steel, load-slip behaviour, ductility, energy-absorbing capacity, and steel-concrete shear bond resistance, the structural performance of ECC-based composite slabs was compared with that of their SCC counterparts. In comparison to SCC equivalents, ECC composite slabs have outperformed them in terms of strength, ductility, energy absorption, and shear bond resistance.

An overview of well-established analysis methodologies for the assessment of building structure fire resistance was provided in the publication "Fire resistance design of composite slabs in building structures: from research to practise" by K. F. Chung and A. J. Wang (30). With the use of these approaches to evaluate the performance of composite slabs under fire, all of the fundamental ideas behind these techniques were exposed and explored. It was highly advised that structural engineers become aware of and proficient in fire-resistant design so they may actively contribute to fire-resistant architecture in the real world.

The fire resistance design of the beam for covered and unprotected case was utilised in Dhara Shah, Janak Shah's (31), "Comparative study of fire-resistant design of steel buildings as per IS800:2007, AS4100:1998, AISC360:2010 and EN1993-1-2," and was compared as per various standards. It was determined that the AISC code provides conservative values since it takes the larger safety factor into account. In addition, while the Indian code provides an affordable value, it confines temperature values to 7500 C, and in the majority of situations involving laterally supported beams, the value of the critical temperature was higher than 7500 C. As a result, it was not recommended to utilise the Indian code. Moreover, the Indian regulation does not clearly depict fire-resistant construction for shielded steel components.

IV. Cognitive Conclusion

The review of literature clearly indicates that:

- Designing a composite deck slab must include three main failure modes: flexure, vertical shear at the support, and longitudinal shear between the steel and concrete.
- The most frequent kind of failure is longitudinal shear failure.
- The interactions at the profiled steel sheet-concrete interface primarily control the performance of a composite slab, which is further influenced by the intrinsic material properties, geometrical parameters, boundary conditions, and manner of external loading.
- The mechanical shear connection, height, form, and orientation of the embossment pattern are the primary determinants of the interfacial shear.

- The use of admixtures/ engineered concrete, site specific engineered profile of steel sheet coupled with parameters affecting the interfacial shear forces enhances in terms of: flexural capacity, stiffness, ductility, energy absorption (vibration resistance), load bearing capacity, fire resistance, and cost effectiveness of composite deck system
- Asymmetrical embossment shapes result in the beginning of end slippage towards the weak side of the embossment, hence symmetrical shapes are advised

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