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Case Study

Exploring deflection challenges: A case study on the influence of heavy concrete weight on profiled steel deck slabs

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ABSTRACT

This paper presents a case study of a deflection challenge in a profiled steel deck slab subjected to heavy concrete loads, as observed during a field investigation. In recent decades, such slabs have gained popularity in both the construction and industrial sectors due to advantages such as being lightweight, cost-effective, quick to install, and capable of resisting natural disasters. However, field observations indicate that when these slabs are subjected to heavy concrete weight, they may experience significant deflection, raising concerns about long-term performance, durability, and serviceability. Excessive deflection can lead to cracking, reduced structural stability, and increased maintenance costs. It is therefore critical to understand the factors influencing deflection by examining key parameters such as material properties, slab geometry, reinforcement detailing, and load distribution characteristics. This study provides a comprehensive assessment of the structural response of such slabs. Field observations suggest that optimizing the L-angle section and C-channel section in areas where the concrete width increases can effectively reduce structural deflection. This approach helps structural elements resist excessive flexural behavior, and when combined with the use of lightweight materials, offers an innovative structural solution that highlights the importance of modern construction practices.

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1. Introduction

In recent decades, steel–concrete composite slabs have become increasingly popular in the construction sector due to the combined advantages of two effective building materials. These composite slabs consist of a profiled steel deck topped with reinforced structural concrete. The decking serves as permanent formwork for the concrete and provides adequate shear bonding while functioning as a composite component. The main advantages of using such slabs include being lightweight, cost-effective, fast to construct, and offering good ductility and seismic performance (Hu and Wang 2017; Wan and Yu 2022; Xiong et al. 2022; Liu et al. 2017; Deng et al. 2022).

Once the concrete has cured and the components of the structural system act together as a composite structural system, the steel deck serves as positive reinforcement. However, certain aspects of composite systems that attract structural experts—particularly reinforcement moments and the formwork required for casting concrete—are often overlooked or significantly minimized during the construction phase. The use of steel deck concrete floors dates back to 1950, when concrete was used as a filling agent over steel decks (Porter and Ekberg 1976).

To ensure composite action, a shear connection is necessary to link the concrete slab with the steel section. Traditionally, this connection is achieved by welding

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steel studs to the steel parts (Shin 2015; Wang and Yu 2017). However, when a composite slab is demolished at the end of its service life, welded shear connections make it difficult to separate the concrete slab from the steel section (Lam et al. 2013).

From a sustainability perspective, traditional construction methods that generate significant waste are becoming less acceptable. Construction and demolition (C&D) waste constitutes one of the largest waste streams globally, accounting for 30% to 40% of total waste (Nair 2024). In India, C&D waste was estimated at 24 million tonnes in 2010 (Shrivastava and Chini 2009), with other estimates suggesting between 11.1 and 14.69 million tonnes generated annually (Raja et al. 2012). Such practices are unsustainable because they not only harm the environment but also affect future generations.

To address this, Lam et al. (2021) proposed an innovative approach involving the use of composite slabs with demountable shear connectors. This design replaces welded connections with bolted ones, allowing the slab to be dismantled at the end of its service life. These connectors function similarly to prefabricated composite structures, improving upon traditional methods for composite element construction (Li et al. 2023).

A critical aspect of composite profiled steel slabs is the bonding behavior between the concrete and steel (Zhu et al. 2012). Studying bonding performance is challenging due to slip behavior at the steel–concrete interface (Shahezad 2014; Patil and Shahezad 2014). The design of the deck slab is also important, as there are three main failure modes: longitudinal shear, vertical shear, and flexural failure (Patrick and Bridge 1993). The strength of a composite slab primarily depends on the connection between the steel sheet and concrete, which governs the longitudinal shear strength. This failure mode determines the ultimate load-bearing capacity of the structure (Siva et al. 2016) and can occur when mechanical connections cannot transfer shear forces until bending failure takes place.

To investigate these shear behavior characteristics, Xian-tie (2011) conducted experimental studies on factors such as slab thickness, sheet thickness, and shear span. The results showed that increasing slab and sheet thickness enhances longitudinal shear capacity, while increasing span length reduces it. Vertical shear failures, on the other hand, occur with shorter spans and increased height under the same loads, particularly near the support region (Kataoka et al. 2017). The shear resistance of composite profiled sheet decking depends largely on the shape of the profile, its height, and the wavelength of the sheeting. Behr et al. (1989) analyzed how various composite structural forms are affected by shear-bearing capacity through both theoretical analysis and experimental testing. Flexural failure is typically associated with excessive deflection, with a peak deflection corresponding to a fraction of the span length.

Other parameters influencing load-bearing capacity and stiffness include slab thickness, sheet thickness, polyurethane foam density, and span length (Qiao et al. 2024). Based on field research, this case study investigates how deflection behavior caused by high-strength concrete in a profiled steel sheet composite slab affects the structural integrity and overall performance.

1.1. Research background

The application of heavy concrete layers impacts the deflection behavior of profiled steel deck slabs, potentially leading to long-term serviceability issues. Excessive deflection can cause cracking, aesthetic concerns, and durability problems (Sun et al. 2024; Porter and Ekberg 1990).

This study investigates deflection challenges in profiled steel deck slabs subjected to heavy concrete loads, focusing on a real-world construction site in Tamil Nadu, India. The selected steel decking system has a span length of 22.87 m, with an external width of 10.61 m on one side and 9.51 m on the other, and a concrete thickness of 127 mm. Fig. 1 illustrates the profile of the steel deck slab at the swimming pool site.

Field visits and virtual observations from real-time construction sites provided an in-depth understanding of how heavy concrete weight influences structural integrity and performance. By analyzing these findings, this case study aims to optimize steel deck slab design and material selection, minimize serviceability failures, and propose effective reinforcement strategies for practical application in the construction sector.

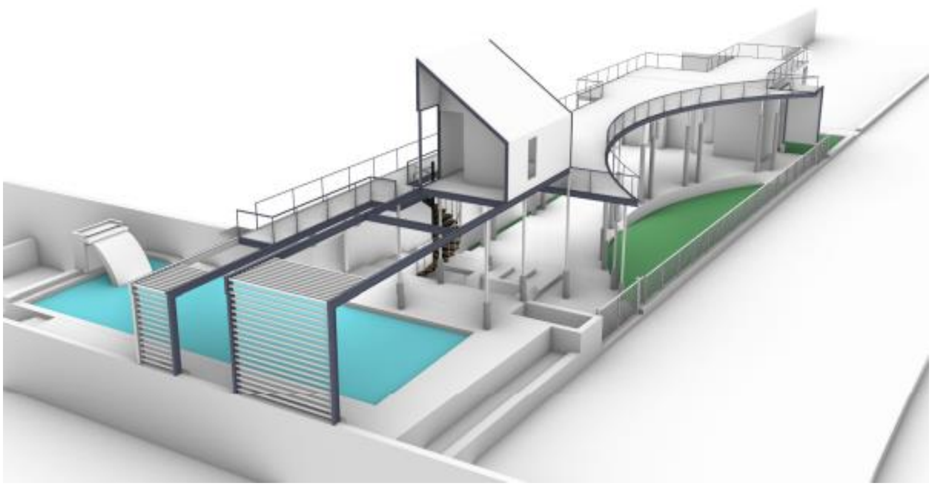

Fig. 1. 3D rendered model of the swimming pool site.

1.2. Research significance

- To understand how heavy concrete weight affects the deflection behavior of steel deck slabs.
- To identify deflection issues that arise from excessive concrete loads.
- To explore potential material alternatives or reinforcement methods that minimize excessive deflection while maintaining structural integrity.

2. Literature Study

As an advanced technology in the construction industry, profiled steel deck slabs are widely used as structural members (Hedaoo and Gupta 2008). The use of slab sheeting helps reduce the quantity of reinforcement steel bars in composite construction systems. Once the concrete has hardened, the steel deck acts as tensile reinforcement for the structure. This type of composite deck slab flooring system is widely used in buildings across the USA and Canada (Schuster 1976).

According to the research board of the Steel Deck Institute (SDI), a standardized procedure exists for composite slab research and testing, providing design criteria based on reinforced cement concrete (RCC) methodologies (Heagler 1993). Based on this study, design recommendations were drafted for long-span composite slabs with deep profiled steel decks, having a depth of at least 200 mm (Brekelmans et al. 1997).

Kubic and Daniels (1979) developed an elastically orthotropic finite element model (FEM) to simulate the behavior of orthotropic steel deck reinforced concrete slabs with uniform thickness. Previous research data effectively predicted the behavior of almost all the models. The research examined a single panel of a typical slab under simply supported and fixed boundary conditions, comparing deflections and bending moments for two-way flexural action versus one-way bending behavior. Additionally, an expression for the optimal aspect ratio of steel-deck-reinforced concrete slabs was proposed. The findings highlight the feasibility of incorporating two-way action in the design process, thereby enhancing structural efficiency.

Nie et al. (2008) examined 13 steel–concrete composite beams, both simply supported and continuous, tested under positive and negative bending. The results indicated that slip at the steel–concrete interface increased deflection by 45% to 90% at 50% of the ultimate load compared to full shear connections. Predictions from Eurocode 4 (EN 1994-1-1 (2004)) and AISC (1999) generally aligned with experimental findings, confirming the feasibility of partial shear connections for achieving structural efficiency while reducing costs and simplifying construction.

Cold-formed sheet behavior in composite deck slabs has also been evaluated using bolted shear connectors. Various profiles were tested for load capacity, deflection, slip, strain energy, and failure modes (Fig. 2). Results show that dovetailed profiles exhibited superior load resistance—5.35% and 22.03% higher than rectangular and trapezoidal profiles, respectively—with lower deflection and slip. Trapezoidal slabs stored the highest strain energy (2.98 kNm) but predominantly failed in shear bond mode. Ductility ratios increased with the rib-to-flange opening width ratio, with trapezoidal profiles showing 36.3% and 55% higher ductility than rectangular and dovetailed slabs, respectively.

Fig. 2. Delamination and end slip in profiled sheet deck slab (Avudaiappan et al. 2021).

He et al. (2019) investigated the structural performance of 26 composite slab specimens with trapezoidal and dovetail profiles, examining the effects of span, end anchorage, and cross-sectional depth. The results indicated that end anchorage significantly enhances load-bearing capacity, although its influence diminishes with increasing span length. Longitudinal shear failure was prevalent in slabs without end anchorage, while slabs with anchorage exhibited either ductile shear or flexural failure. Increasing the thickness of profiled steel sheets and adding reinforcement at the troughs improved bearing capacity and slip resistance, although gains in rigidity were minimal. Overall, dovetail-profiled slabs outperformed trapezoidal ones in long-span flooring systems, offering superior structural efficiency (Gholamhoseini et al. 2014).

The literature review highlights that limited experimental research has been conducted on the time-dependent, in-service behavior of concrete composite slab sections. While advancements in permanent formwork techniques have been made, there is little guidance on calculating long-term deflection. Additionally, Gilbert et al. (2012) determined that the presence of a steel deck slab slightly influences the drying shrinkage profile across the thickness of the composite slab, thereby affecting its overall long-term performance.

3. Effects of Heavy Concrete Weight on Structural Deflection

With an emphasis on mid-span serviceability, Jaffar et al. (2015) examined the impact of geopolymer concrete infill on the Profile Steel Sheeting Dry Board (PSSDB) system with the half board (PSSHB). Due to its higher compressive strength, geopolymer concrete was selected, and an OPC-free composition was used in a modified PSSHDB panel. Experimental results demonstrated that the geopolymer infill improved the stiffness and performance of the system, reducing mid-span deflection by 41%.

In profiled sheet slabs, the use of heavier concrete, which increases deflection, has led to a stronger focus on serviceability considerations in design, particularly when using higher-strength concrete and shallower sections, as studied by Lamport and Porter (1990). In current composite concrete slab construction, thin-walled, cold-formed profiled steel decking plays a critical role, and significant research has been conducted using analytical, numerical, and experimental methods.

Many design codes, such as IS 801 (1975), Eurocode 3 (EN 1993-1-1, 2001), BS 5950-1 (1995), AS/NZS 4600 (2005), and AISI (2007), address various aspects of steel deck design, including limitations related to bending moment, web crippling, and distortional buckling. Indian Standard IS 801-1975 specifies the design of steel decks, whereas Eurocode 3 (EN 1993-1-1, 2001) and AS/NZS 4600 (2005) present improved techniques such as the Direct Strength Method (DSM) for cross-section capacity prediction. The AISI (2007) specification refines calculations for distortional buckling, combined bending, and torsional stress by integrating Allowable Stress Design (ASD), Load and Resistance Factor Design (LRFD), and Limit State Design (LSD) methods. BS 5950-1 (1995) emphasizes balancing safety and material efficiency while also incorporating factors such as local buckling, torsional-flexural buckling, and material non-linearity in a structured manner.

Studies by Hedaoo and Gupta (2008) indicate the need for further investigation into bending moments, internal responses, and embossment effects, with finite element methods showing strong potential for addressing these research areas.

4. Improving Load–Slip Behavior and Strengthening Composite Slabs

Shahezad (2014) investigated the shear bond behavior of lightweight aggregate concrete composite slabs commonly used with profiled steel sheets to improve performance. The research indicates that various types of concrete and strengthening techniques can enhance the load–slip behavior of composite construction. Additionally, the use of stainless-steel decks has been shown to offer higher strength and corrosion resistance, making them a valuable alternative for long-term durability.

In one study, three types of profiled steel sheet composite concrete slabs (PSSCCS)—with studs, with minimum reinforcement, and without reinforcement—were tested under static loading. The results indicated that slabs with reinforcement and studs exhibited two to three times higher load-carrying capacity than non-reinforced slabs. Failure modes, including shear bond failure, bending failure, and end-slip, were analyzed, revealing that shear studs enhance composite action by preventing debonding. Load–deflection curves demonstrated increased linearity in stud-reinforced slabs prior to shear bond failure. Analytical models aligned well with experimental findings, accurately predicting structural behavior. Increasing the thickness of steel sheets further enhanced slab strength, making PSSCCSs a viable solution for high-rise buildings (Islam et al. 2020).

Controlling slippage in composite deck slabs is crucial, as it directly impacts central deflection and overall structural stability (Vohra and Dhankot 2015). To address failure mechanisms, one study introduced a reinforced concrete infill strengthening method, effectively delaying premature failure modes. Furthermore, Bavan and Baharom (2014) proposed a novel approach for predicting short-term deflections in composite cold-formed steel decks, demonstrating significant improvements over conventional methods and ensuring better performance and serviceability.

5. Methodology

The procedure for this case study, following a structural approach, is illustrated in Fig. 3 as a flowchart diagram.

6. Profiled Steel Deck Specifications

A composite structural system consists of a profiled galvanized iron (GI) decking sheet, reinforced concrete, structural steel elements, and shear connectors to achieve effective composite action. Fig. 4 shows a section view of the concrete slab, designed using M30-grade concrete (Table 1), which provides compression resistance and structural integrity. Reinforcement is provided by 8 mm diameter bars positioned to resist tensile stresses.

The structural steel framework includes primary and secondary I-beams that support the composite slab. Figs. 5 and 6 illustrate the main I-beams (8″×4″) acting as the primary load-bearing members, distributing loads to the supporting columns, while the secondary I-beams (4″×2″) transfer loads from the slab to the main beams, minimizing deflection. Additional structural support is provided by C-channel sections (3″×1.5″), which enhance lateral stability, and L-angles (1″×1″), which reinforce slab edges and connection points.

To ensure proper composite behavior, shear connectors—typically in the form of shear studs—are installed at the steel–concrete interface to prevent slip and enhance load transfer efficiency.

Key observations include flexural failure due to bending, shear bond failure at the interface, and brittle failure in extreme cases. The inclusion of shear connectors significantly improves load-carrying capacity by minimizing slip and increasing ductility, while reinforcement enhances flexural resistance.

The advantages of this system include:

- Structural efficiency by eliminating the need for temporary formwork.
- Enhanced strength through composite action.
- Cost-effectiveness by reducing material consumption.
- Improved durability due to the steel–concrete interface.

These benefits make profiled steel deck composite slabs ideal for high-rise buildings, industrial structures, and bridges where strength, speed, and economic feasibility are critical design considerations.

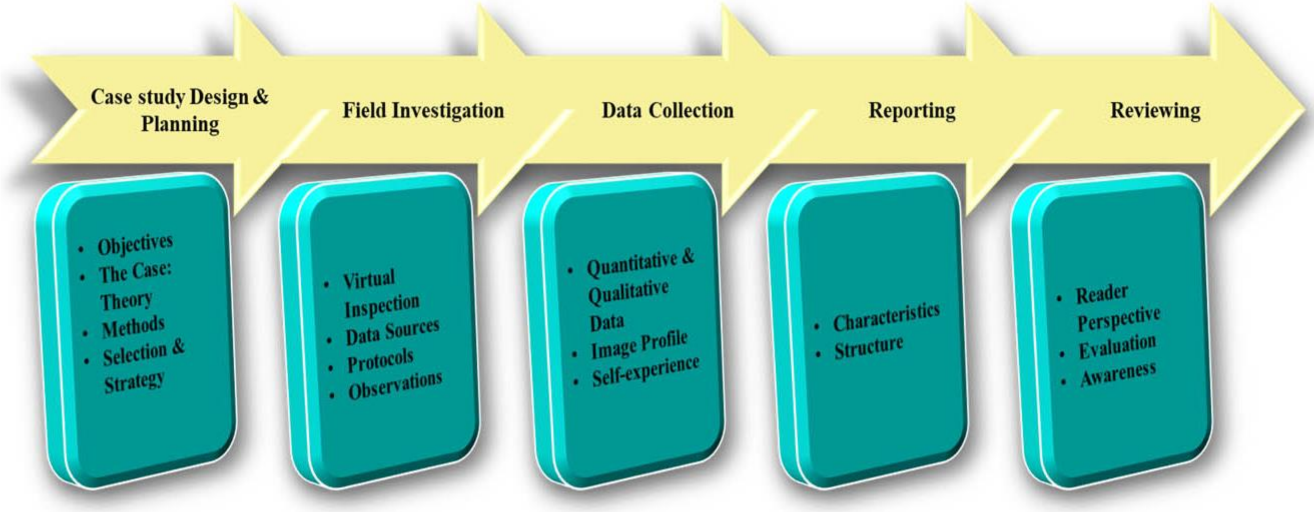

Fig. 3. Stepwise approach to case study investigation.

Table 1. Concrete mix properties.

Property	Specification	Remarks
Grade of concrete	M30 (30 MPa or 300 kg/cm^2)	Based on the characteristic compressive strength at 28 days
Nominal mix ratio	Design mix as per IS 10262 (2019)	Mix proportion determined by lab trials
Cement content	350–450 kg/m^3	Min. 300 kg/m^3 as per IS 456 (2000)
Water-cement ratio	0.40–0.45	Adjusted based on workability and exposure conditions
Fine aggregate (sand)	600–800 kg/m^3	Well-graded sand (zone II or III as per IS 383 (2016))
Coarse aggregate (20 mm)	1200-1350 kg/m^3	Crushed angular aggregates preferred
Water content	150–180 litres/m^3	Based on workability requirements
Admixtures (if used)	Superplasticizer (0.5–1% by cement weight)	Improves workability and reduces water demand
Slump value	75–125 mm	Depends on placement method (pumped/hand-placed)
Compressive strength	30 MPa (at 28 days)	Achieved under standard curing conditions
Curing period	Min. 7 days (with curing compounds) Min. 14 days (for normal curing)	Longer curing enhances durability as per IS 456 (2000)

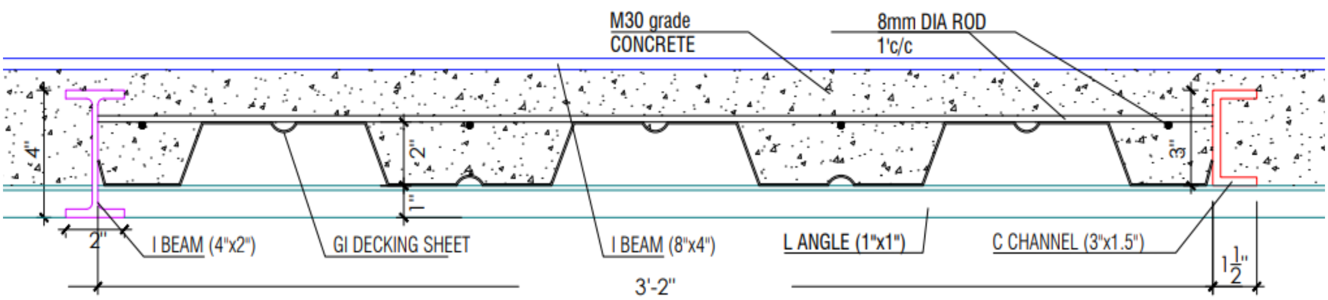

Fig. 4. Sectional view of profile sheet.

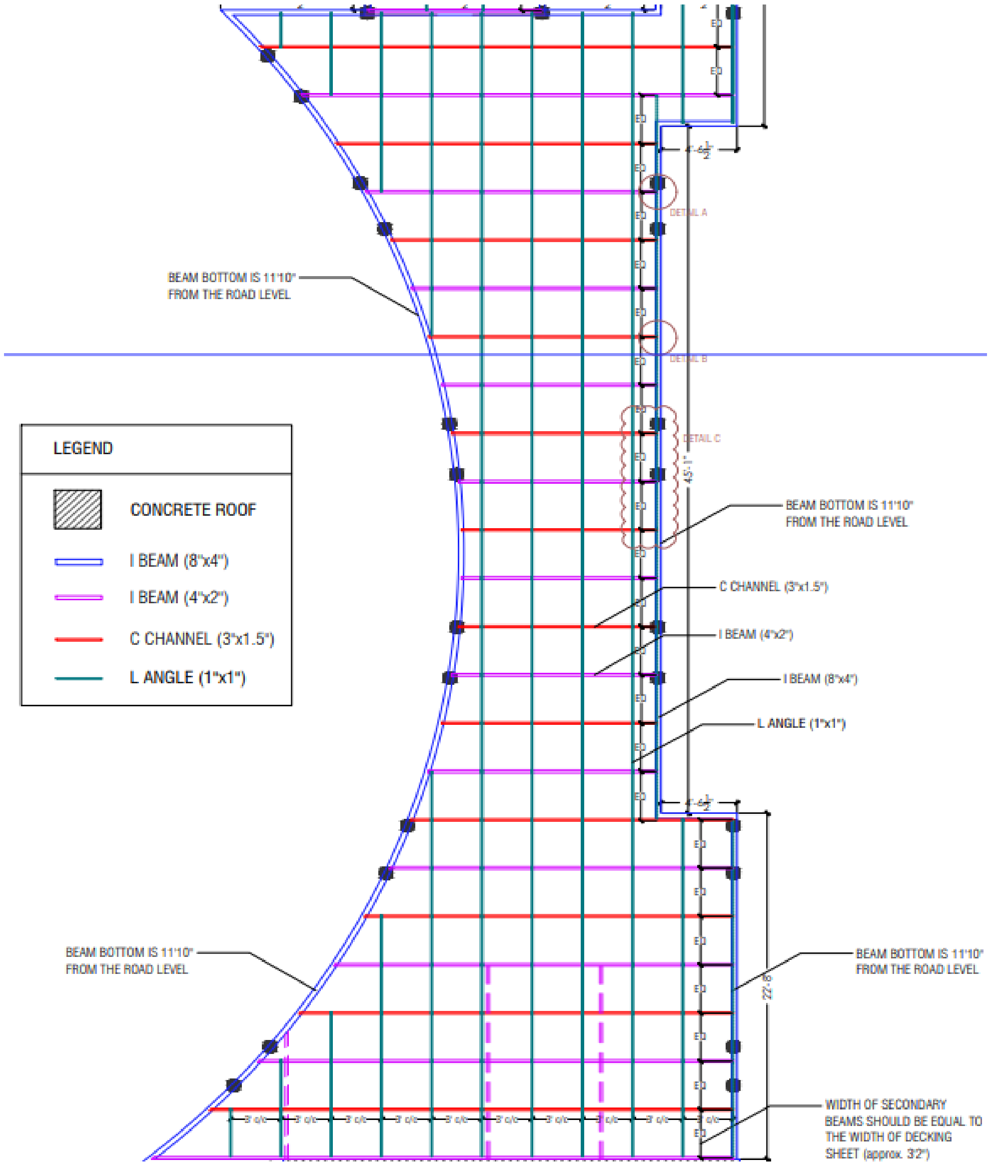

Fig. 5. Plan view of details of the deck slab.

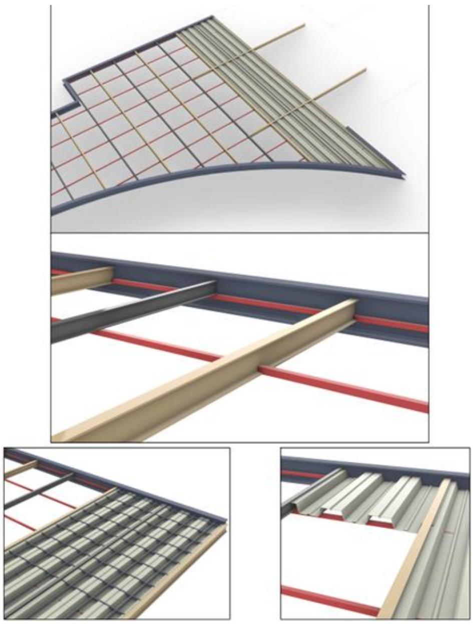

Fig. 6. 3D view of deck slab detailing.

6.1. Proposed design criteria

Moments of inertia for rectangular section;

$$I = \frac{bd^3}{12} \quad (1)$$

Maximum deflection;

$$\delta_{im} = \frac{5wl^4}{384EI} \quad (2)$$

Long-term deflection;

$$\delta_{tt} = \lambda\delta_{im} \quad (3)$$

where:

- λ is the creep coefficient, which depends on the concrete age and loading duration.
- Typical values for creep coefficient (λ);
  Short-term (1 month) : λ=1.2–1.5
  Medium-term (6 months to 1 year) : λ=2.0–2.5
  Long-term (5+ years) : λ=2.5–3.0

7. Cause of Structural Issues

Based on on-site observations and structural virtualization, it is evident that the composite deck slab experienced significant deflection due to its inability to adequately withstand the applied concrete loads, as shown in Fig. 7. This issue was particularly pronounced in areas with larger span widths, where increased bending stresses were observed. The slab is supported by a combination of structural members, with longitudinal and transverse supports intended to distribute loads effectively. However, the observed excessive deflection suggests that the existing support configuration does not provide sufficient flexural rigidity, resulting in structural deformation beyond permissible limits.

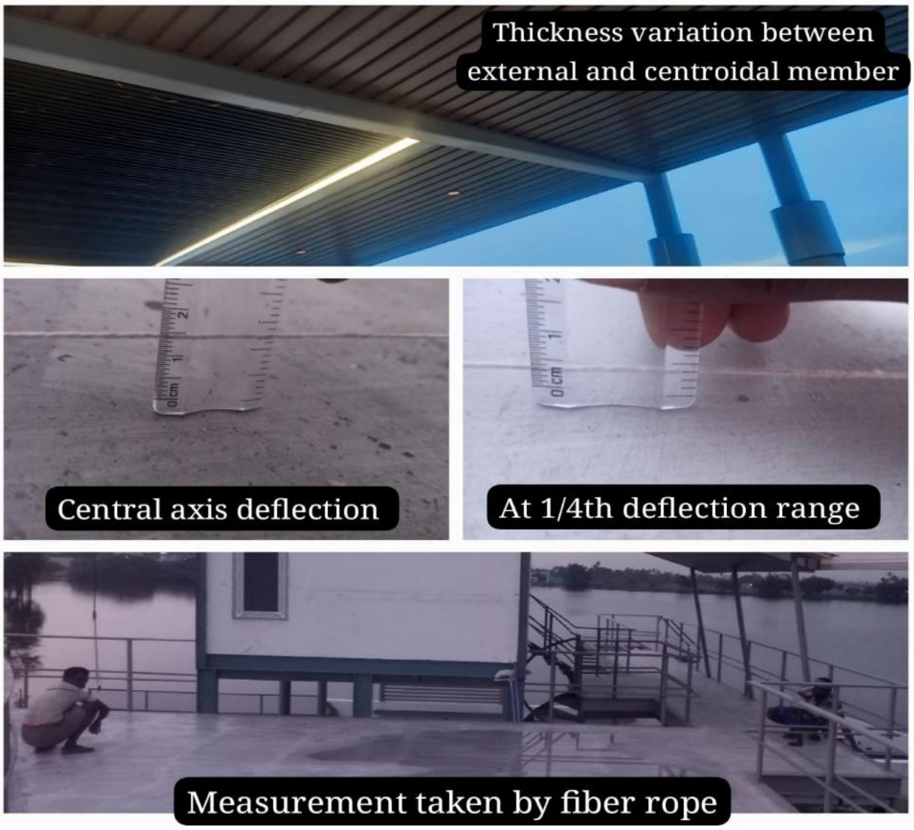

Fig. 7. Field deck slab deflection.

A critical factor contributing to this issue is the non-uniform load distribution caused by variations in slab thickness between external and central regions. This imbalance likely induced differential bending stresses, leading to localized weaknesses in the slab. The deflection was further exacerbated after the placement of terrace tiles, which involved layering waste aggregate, moisture conditioning for compaction, and applying mortar with a low water–cement ratio. The additional weight from this process intensified bending deformations, particularly above the galvanized iron (GI) decking sheets. Once the deflection became visibly apparent, corrective measures were immediately implemented by removing the waste aggregate layer, which helped reduce bending to some extent. However, residual structural deformations remain, indicating the need for further assessment and reinforcement.

Several technical deficiencies likely contributed to this anomaly. An inadequate structural system and improper or excessive reinforcement may have reduced the slab's flexural rigidity. In addition, the composite action between the concrete and steel deck is a critical factor in such systems. Any insufficiencies in shear connection can cause inadequate interlocking or reduced bonding between materials, resulting in ineffective load transfer and increased deflection. Furthermore, material-related issues such as improper mix proportioning, inadequate curing conditions, or uneven reinforcement placement may have weakened the slab's performance under service loads.

Long-term environmental factors have also influenced the structure's performance. Over time, deflection may have been gradually induced by thermal expansion, shrinkage, and differential settlement of supporting materials. On-site deflection measurements confirm departures from design tolerances, especially at the central axis and at one-fourth of the span length, highlighting the necessity for structural intervention.

A comprehensive structural assessment—including finite element analysis (FEA) simulations and in-situ load testing—is required to evaluate the slab's actual performance under service conditions. To restore serviceability and ensure compliance with safety regulations, strengthening techniques such as additional reinforcement, structural retrofitting using external post-tensioning, or polymer-based overlays should be considered.

8. Conclusions

This case study determined that inadequate structural components combined with the excessive weight of concrete were the primary causes of deflection in the profiled sheet deck slab. Excessive deflection compromises the serviceability of the structure and poses a risk to its long-term durability. Inefficient load transfer can result from several contributing factors, including variations in slab thickness, insufficient reinforcement detailing, and inadequate shear connections between the concrete and steel deck.

The flexural stiffness required to resist bending forces—particularly over larger spans—was found to be insufficient in the current support configuration. Site observations indicated that this problem was further aggravated by the additional weight of terrace tiles, moisture retention, and mechanical applications, which induced localized bending deformations. In response, corrective actions were taken by removing these additional materials, leaving the slabs finished only with concrete surfaces. This outcome reinforces the need for detailed structural evaluation and targeted reinforcement strategies.

To improve performance, it is recommended that structural components be enhanced through the use of L-angle and C-channel sections, which can increase flexural stiffness and reduce excessive bending, especially in areas with greater slab width. Verification of the slab's performance should be conducted through comprehensive finite element analysis (FEA) and in-situ load testing. Strengthening measures such as external post-tensioning and polymer-based overlays should also be considered to enhance stability, ensure compliance with safety standards, and extend the service life of composite deck slabs in modern construction.

Suggestions:

This study observed that the current design approach for such structures is relatively simple and lacks provisions for future adaptability or enhancement. Therefore, engineers should perform detailed structural analyses before initiating composite slab projects to ensure optimal performance. Alternative reinforcement strategies—such as double-layer steel mesh or Fiber-Reinforced Polymer (FRP) bars—should be explored to reduce the overall density of the slab. In parallel, research into lightweight aggregates as a substitute for natural aggregates could help lower concrete weight and improve long-term serviceability. Additionally, all structural details should be enriched and validated using structural design software to ensure consistency with intended performance requirements.

Note:

While clients may prioritize an architectural design that conveys luxury and aesthetics, structural engineering must ultimately prioritize safety, durability, and long-term stability.

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Conflict of Interest

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Author Contributions

All of the authors made substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data; were involved in drafting the manuscript or revising it critically for important intellectual content; and gave final approval of the version to be published.

Data Availability

The datasets created and/or analyzed during the current study are not publicly available, but are available from the corresponding author upon reasonable request.

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