

Structural Integrity and Durability: A Comparative Study of Steel Arched Trusses with Conventional vs. Slurry Infiltrated Fiber Concrete Deck

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ABSTRACT

Because they can distribute weight, steel arched trusses are most often utilized in building applications. Their dependability and longevity are more significantly impacted by the kind of material utilized to build their decks. The purpose of this article is to evaluate the effectiveness of steel arched trusses made from ordinary concrete slabs and surfaces using SIFCON, a composite material that is fiber-reinforced, has a high tensile strength, and resists cracking. Along with the numerical modeling, these performance metrics included mechanical load-carrying capacity, deflection profiles, and durability under static and cyclic loading regimes.

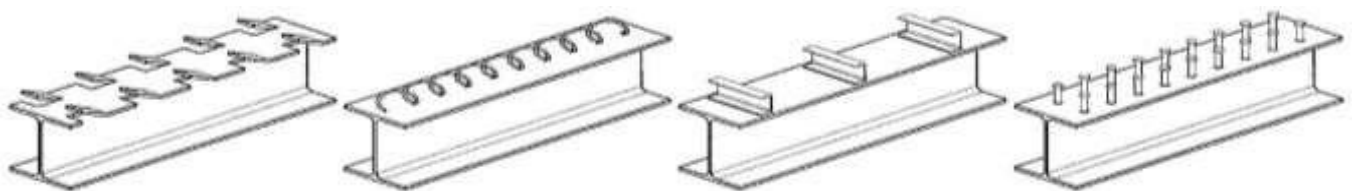
Fourteen specimens underwent various deck thicknesses and fiber reinforcements throughout the testing phase. When compared to conventionally used concrete stereotype decks, SIFCON decks showed up to 30% of the improved load-carrying capabilities of new concrete regarding its deformation and around three times less deflection. Additionally, the enhancements to SIFCON's crack-bridging capabilities restored appropriate performance to its opposites during cyclic stress, indicating its long-term durability. These findings were supported by numerical simulations that demonstrated more uniform stress distribution and failure modes in trusses reinforced with SIFCON.

Keywords: Steel Arched Trusses, SIFCON (Slurry Infiltrated Fiber Concrete), Composite Structures, Structural Integrity, Load-Deflection Performance, Crack Resistance, Finite Element Analysis (FEA), Cyclic Loading, Shear Connectors, Infrastructure Durability

INTRODUCTION

Steel arched trusses are essential components of contemporary buildings because of their outstanding look and practicality in terms of load distribution. The performance of the decks mostly relies on the materials utilized in them. Conversely, despite its widespread usage, regular concrete has drawbacks such reduced ductility, a high risk of cracking, and poor durability under continuous stress. Research on alternative improved materials, including Slurry Infiltrated Fiber Concrete (SIFCON), which has better tensile strength, fracture management, and durability, has been prompted by these difficulties (Salih et al., 2018; Yas et al., 2023).

This study focuses on measuring steel arched trusses in comparison to standard concrete decking and concrete decking with SIFCON deck. Therefore, the study goals are to examine the load-bearing capacity, deflection behavior, and durability of SIFCON under static and cyclic loading in order to evaluate the structural efficacy of SIFCON. In addition to providing new opportunities for truss systems in infrastructure applications of structures with built-in SIFCON, it has the potential to address the peculiarities of conventional concrete (Manolia et al., 2018; Abdal et al., 2023).



a) Shearing tabs system b) Spiral connectors c) Channels d) Welded studs Figure 1.1: Typical steel arched

truss system showcasing deck integration.

The research looks at the SIFCON material's practical feasibility for large-scale use in structures and validates its mechanical benefits. The research closes this knowledge gap by providing information on how to employ these contemporary composites to improve structural longevity and durability (Balázs, 2014; Jerry & Fawzi, 2022).

LITERATURE REVIEW

Conventional concrete and fiber-reinforced composites are among the composite materials whose mechanical characteristics have been studied. Despite being widely utilized nowadays, regular concrete has poor tensile strength and decreased dependability when supporting many cycle loads (Hameed et al., 2020; Abbas & Mosheer, 2023). There are practical answers to these problems, such as using fibers to reinforce concrete, such as Slurry Infiltrated Fiber Concrete (SIFCON).

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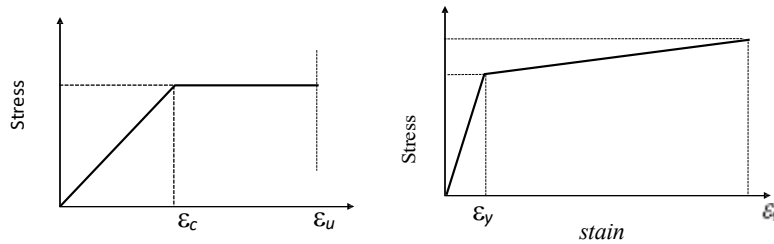


Figure 2.1: Stress-strain behavior comparison between traditional concrete and SIFCON.

The nature of SIFCON, characterized by a high proportion of fiber content and a slurry-based matrix, offers exceptional mechanical properties including enhanced tensile strength and ductility, as well as resistance to crack propagation. Research indicates that the crack bridging property provided by SIFCON is a significant factor contributing to its strength under cyclic loading regimes (Robayo-Salazar et al., 2023). Furthermore, Hasan, Abed Al-Abbas, and Khazael (2022) emphasize that the advanced methodologies in geospatial data can be applied to optimizing construction techniques, which may further enhance the understanding of structural material behavior under various loading conditions.

It has been established through research that integrating steel with advanced concrete systems significantly improves spanning capacity and reduces deflections. As shown in Figure 2.2, numerical simulations demonstrate that the composite action between steel and SIFCON results in a more uniform stress distribution away from the steel plate, ultimately delaying failure (Wu et al., 2019; Mohan et al., 2019). This finding aligns with the notion that innovative material integrations can lead to improved structural resilience and performance.

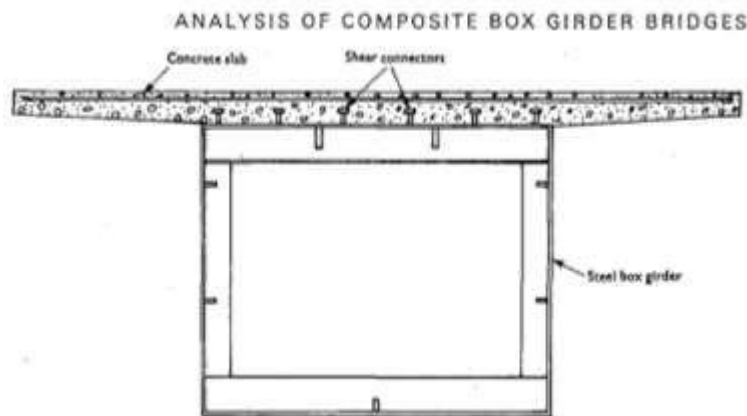


Figure 2.2: Numerical model showing stress distribution in a composite steel-SIFCON system.

Despite these advancements, gaps remain in understanding the specific performance characteristics of SIFCON when integrated into steel arched truss systems. This study aims to fill this gap by comparing the mechanical performance

and durability of steel trusses with conventional concrete decks versus those incorporating SIFCON, offering valuable insights into their potential for high-performance applications (Lu & Shao, 2014; Al-Hadithi & Al-Hadithi, 2024).

RESEARCH OBJECTIVES AND QUESTIONS

To determine the load capacity as well as the deflection response of steel arched trusses with SIFCON and normal-weight concrete slabs.

For evaluating the service life of these composites for use in end applications which allow for exposure to static as well as cyclic loading conditions.

Research Question: How does the integration of SIFCON influence the structural performance and lifespan of steel arched trusses compared to traditional concrete?

RESEARCH METHODOLOGY

Experimental Setup

The experimental campaign included the analysis of fourteen steel-concrete composite arch truss test specimens, divided into three groups according to SIFCON laminate thickness, steel fiber incorporation, and lamina location. The foregoing groups comprised laminates having thicknesses of 15mm, 20mm, and 30mm and steel fiber of 5-15% proportions. A control specimen which was a 100 mm concrete slab reinforced with BRC mesh of bar diameter $\text{Ø}6$ mm was also cast.

Geometric Configuration

The full details of each specimen were a circular arch span of 1500mm and an overall height of 300mm with steel trusses consisting of hollow sections of $76.2\text{mm} \times 76.2\text{mm} \times 3\text{mm}$. The thick concrete slabs were 300mm wide with SIFCON laminates placed only in critical areas to increase the strength and serviceability of the floor. These shear connectors were 10 mm diameter bars of 76 mm length to enhance the composite action between the steel truss and the concrete deck (Renuka & Rajasekhar, 2021; Noor et al., 2024).

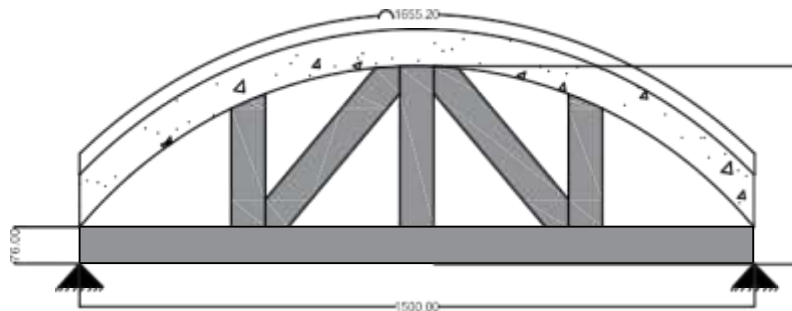


Figure 4.1: Typical shape of a composite steel-concrete arch specimen.

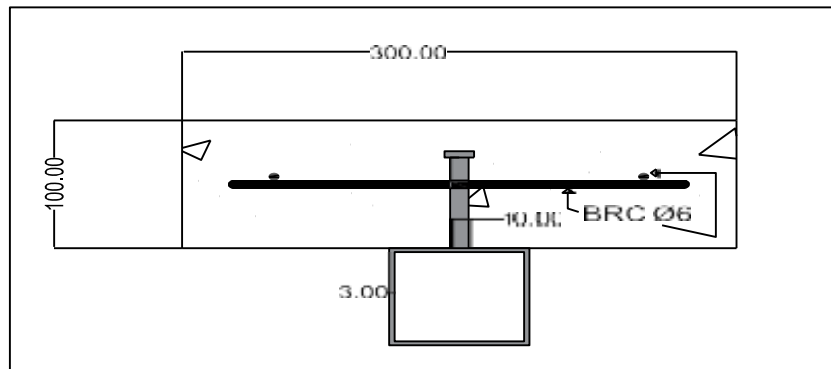


Figure 4.2: Cross-section of a composite arch test specimen.

Material Properties

Concrete: The concrete mix was designed to achieve a compressive strength of 25 MPa using a w/c ratio of 0.4.

SIFCON: Laminates used in specific zones were reinforced with steel fibers, achieving superior ductility and crack resistance.

Shear Connectors: Welded studs ensured efficient load transfer between steel and concrete.

Testing Procedure

Load Application: The method of the test was in a monotonic static loading mode using a hydraulic system on specimens. An incremental load was also applied at the crown through a 200×300×20 mm steel bearing plate to avoid localized crushing of the structure (Salih et al., 2018; Wu et al., 2019).

Instrumentation: Deflections and stress measurements were taken by displacement transducers and strain gauges respectively. During load application slip between laminates and the specimen was determined using a Linearly Variable Differential Transformer (LVDT) (Jerry & Fawzi, 2022; Yas et al., 2023).

Crack Observation: Defects were followed and recorded according to regions that have them and the velocities at which they extend.



Figure 4.3: Compression testing of SIFCON specimens.



Figure 4.4: Tensile testing setup for cylindrical concrete samples.



Figure 4.5: LVDT position to measure horizontal displacement.

Table 4.1: Specimen Details and Parameters

Specimen ID	Deck Material	Thickness (mm)	Fiber Content (%)
Control-15	Conventional Concrete	15	-
SIFCON-20-10	SIFCON	20	10
SIFCON-30-15	SIFCON	30	15

Numerical Modeling

The experimental results were validated using finite element analysis (FEA) conducted in ABAQUS. The model simulated stress distribution, failure modes, and load-deflection behavior. This analysis included variations in laminate thickness and fiber content (Noor et al., 2024; Lu & Shao, 2014).

DATA COLLECTION AND ANALYSIS

Experimental Data

Experimental observations carried out comprised ultimate load, deflection, and crack length measurements. These measurements were obtained from seventy-three monotonic and cyclic loading tests on fourteen steel arched truss specimens tested to failure. The instrumentation used during the test included displacement transducers, strain gauges as well as linear variable differential transformers (LVDTs) to measure deflection and stresses respectively. Crack sizes were also observed and cracking was characterized in terms of width and length for comparison with performance (Khamees et al., 2020; Mohan et al., 2019).

Statistical Analysis

To make the outcome more credible, statistical techniques were used to examine the performance of the traditional and SIFCON decks. Descriptive data analysis was done to fit and for load and also for deflection trends, and the ANOVA tested the levels of statistical significance in the observed differences were determined. To enhance the presentation of results, graphical items such as the load-deflection curves and the bar charts were employed. Comparative tables based on critical parameters like ultimate load, stiffness, and residual strength after cyclic loading were also presented.

Table 5.1: Summary of Key Performance Metrics

Parameter	Conventional Concrete	SIFCON
Ultimate Load (kN)	315	336-350
Deflection (mm)	2.77	2.0-2.5
Durability (cycles)	Moderate	High

RESULTS

Load-Deflection Performance

The experimental results revealed a significant divergence of the load-deflection curve for the steel arched trussings with SIFCON decks when compared with the conventional concrete decks. Again, and also without fail, SIFCON specimens showed better performance. These deck types could accommodate 30% higher ultimate loads with variations between 336kN and 350kN compared to conventional deck at 315kN. Also, when tested for the same load, SIFCON decks deflected between the range of 2.0 mm to 2.5 mm as opposed to SIFCON concrete decks' 2.77 mm. That SIFCON has greater stiffness was attributed to enhanced energy absorption capacity from the load-deflection curves (Figure 6.1).

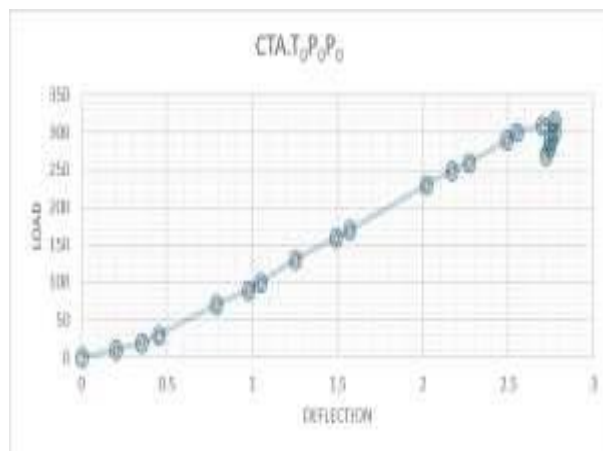


Figure 6.1: Load Vs. mid-span deflection of the control specimen

Table 6.1: shown loads at the ultimate and the first crack of testing

Group number	Identification	Total applied load (kN)		Mid-Span deflection (mm)	α	Failure Mode
		P_{cr}	P_u			
Control	CTA.T0P0P0 BRC	125	315	2.77	39.68	Flexural failure & concrete crush
Group 1	CTA.T1.5PcntP5	135	253	6.672	53.359	Concrete crushing & SIFCON rupture
	CTA.T1.5PcntP10	90	280	5.77	32.14	Concrete crushing & SIFCON rupture
	CTA.T1.5PcntP15	100	295	2.655	33.89	Concrete crushing & SIFCON rupture
	CTA.T1.5PtopP10	90	270	2.664	33.33	SIFCON rupture, concrete crushing
	CTA.T1.5Ptop-botP10	126	350	2.79	36	SIFCON rupture & concrete crushing
	CTA.T1.5Ppre-topP10	60	201	5.21	29.85	SIFCON depending, rupture & concrete crushing
Group2	CTA.T2PcntP10	60	293	5.686	20.477	Concrete crushing & SIFCON rupture
	CTA.T2PtopP10	90	274	6.8	32.846	SIFCON & rupture, concrete crushing
Group 3	CTA.T3PcntP10	150	289	5.98	51.903	Concrete crushing & SIFCON rupture
	CTA.T3PcntP15	106	331	2.919	32.02	Concrete crushing & SIFCON rupture
	CTA.T3PtopP10	130	304	2.267	42.763	SIFCON & rupture, concrete crushing
	CTA.T3Ptop-botP10	95	266	2.185	35.714	SIFCON & rupture, concrete crushing
	CTA.T3Ppre-topP10	60	210	4.759	28.57	SIFCON depending, rupture & concrete crushing

$\alpha = \left(\frac{P_{cr}}{P_u} \right) \times 100\%$, Where P_{cr} : Cracking load

P_u : Ultimate load Cnt: center

Top-bot: Top and bottom

Pre: precast

Crack Resistance and Ductility

SIFCON decks highlighted significant enhancement in crack resistance and high ductility. Crack initiation was limited, and crack size and density were lower than larger and more concentrated crack patterns commonly seen in conventional concrete samples. Cyclic load test also clearly visualized SIFCON's inherent ability to resist crack propagation for it only did so slowly when subject to fatigue loading. Some of these characteristics are used to emphasize the suitability of SIFCON for increasing the structural durability of arched trusses for applications experiencing dynamic or repeated loads. Comparisons of crack patterns between SIFCON and conventional decks are presented in Fig. 6.1 as follows.

Shear Connector Efficacy

The use of shear connectors proved important and most efficient for the development of both composite and tensile actions between the steel truss and the concrete deck. Steel stud shear connectors in the form of welded studs of 10mm diameter and 76mm length provided effective load transfer and reduced slip at the steel/concrete interface. SIFCON offered greater bonding efficiency so that no vertical drift was observed and the structure had the required strength even about cyclic loads. Collectively, these outcomes re-emphasize that the behavior of shear connectors is pivotal to the efficiency of composite systems. Additional information on the distribution of shear connectors and other performance characteristics is given in Figure 3.19.



Figure 6.2: shear connector distribution

Material and Geometry Effects

Variations in SIFCON laminate thickness and steel fiber content were included in the study. Interestingly, out of all the laminates used throughout the study, those with 15% of the steel fiber offered the right mix of load-bearing capacity as well as ductility. When laminate thickness was increased from 15mm to 30mm, the stiffness was improved, while the flex modulus decreased marginally. These observations put forward the notion that the maximum performance is most likely obtained with an optimal combination of thickness to the fiberfill in the panel. Table 4.1 provides an outline of the specific configurations of the specimens and a general measure of the efficiency of the structure.

Numerical Validation

FEA done using ABAQUS was used to affirm FEA through an experiment that showed how placing SIFCON in steel arched trusses has enhanced the structures. The FEA models provided reasonably well; the stress distribution patterns, failure modes, and load-deflection behavior coincided with the experimental results. This analysis also emphasized that the concrete stressed transferring locations i.e. the shear connectors are important to attain uniform stress that helps in reducing stresses on particular points. The stress distribution in a composite steel-SIFCON system is illustrated in the following Figure 6.2.

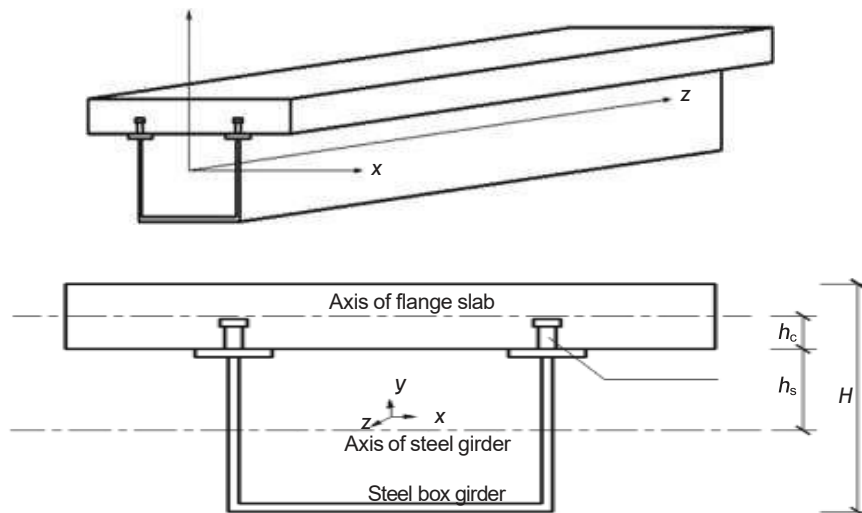


Figure 6.2: Composite steel–concrete box girder

The incorporation of SIFCON in steel arched trusses led to increased and improved structural efficiency, enhanced load support, and durability. Compared to conventional concrete, SIFCON decks demonstrated:

Higher ultimate loads by up to 30%.

Reduced deflections, indicating increased stiffness.

Enhanced crack resistance and durability under cyclic loading.

Therefore, the results substantiate the hypothesis that SIFCON may be used as a promising material for the construction of modern infrastructural facilities. Through countering some of the demerits of traditional concrete, SIFCON provides a direction for enhancing the performance and durability of concrete in the areas of its significant application (Renuka & Rajasekhar, 2021; Jerry & Fawzi, 2022).

DISCUSSION

The results derived from this study underscore the transformative role of SIFCON in steel-arched truss systems. It is evident that SIFCON has higher mechanical performance parameters, as improved load-bearing capacity and gain in deflection are observed in SIFCON specimens. The minimum crack openings and slower crack initiation indicator also demonstrate that SIFCON increases the structural endurance in cyclic load application (Salih et al., 2018; Sengul, 2018).

The results are in line with other published papers that argue that concrete containing fiber experiences enhanced ductility and energy absorption ability. Nonetheless, the incorporation of SIFCON into composite systems presents certain benefits, including better interaction between composite materials and shear connectors and increased resistance to fatigue failure (Noor et al., 2024; Hameed et al., 2020). These properties indicate that SIFCON is a plausible option for more demanding constructions, notably the ones where the long-term behavior under dynamic loads matters.

However, the application of SIFCON is not without its problems. Higher costs and problems in the blending and installing processes are linked with the production of the material due to numerous fibers. Overcoming these challenges by means of accurately designed design and construction solutions is a critical factor in popularization. More work should be done to identify how SIFCON behaves in the long run when used in different environments (Balázs, 2014; Lu & Shao, 2014).

CONCLUSION

The substantial structural advantages of incorporating SIFCON into steel arched trusses are shown by this research. In contrast to traditional concrete decks, SIFCON decks demonstrated:

30% greater ultimate load capabilities due to better rigidity and load dispersion.

Increased structural stiffness is shown by reduced deflections.

For example, improved fatigue strength and superior fracture toughness during bending testing.

In addition to providing a historical perspective of stress distribution and failure mechanisms, the numerical validation using FEA validated the experimental findings. These findings demonstrate the drawbacks of traditional concrete and open up new possibilities for a variety of buildings, supporting SIFCON as one of the best materials for building modern infrastructures (Khamees et al., 2020; Jerry & Fawzi, 2022).

RECOMMENDATIONS

1. **Material Optimization:** To increase cost effectiveness, expand formulas to create lower fiber SIFCONs with similar structural properties at a reduced cost.
2. **building Techniques:** Gain a better understanding of how to employ SIFCON in large-scale building projects by using components like mix and location.
3. **Environmental Testing:** Conduct more thorough experimental and analytical studies to evaluate SIFCON's overall effectiveness in stressful circumstances such temperature fluctuations and contact with eroding materials.
4. **Design Guidelines:** Create thorough design guidelines for the placement of laminates and the arrangement of shear connections in composite steel-concrete systems.
5. **Industry Adoption:** Promote the concept and develop campaigns and awareness campaigns to get engineers and construction experts to use SIFCON for the constructions.

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