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Selection of the Optimal Cross-Sectional Shape of Profiled Steel Decking for Steel–Concrete Composite Floor Systems

Qosimov To'raboy[1], Ulugberdiev Sanjarbek Shaydullayevich[2], Bakhriev Nuritdin Fakhritdinovich[3]

Abstract

Steel–concrete composite floor systems incorporating profiled steel decking and cast-in-place concrete slabs are widely used in modern building construction due to their structural efficiency, reduced material consumption, and accelerated construction schedules. However, the geometric optimization of profiled decking remains insuffi-ciently investigated, particularly with regard to the influence of flange width ratios on flexural stiffness and load-bearing capacity at different stages of structural perfor-mance.This study investigates the optimal cross-sectional configuration of profiled steel decking by analyzing the relationship between the widths of the upper and lower flanges, decking height, and wave length. Analytical expressions for the centroid lo-cation and moment of inertia are derived, and optimization criteria are formulated for both the installation stage (prior to concrete hardening) and the service stage (compo-site action). The results demonstrate that maximum flexural stiffness during installa-tion is achieved when the top and bottom flange widths are equal, resulting in a sym-metric cross-section. In contrast, during the operational stage, the optimal flange width ratio depends strongly on the magnitude of the live load. Practical recommen-dations are provided for the orientation and design of asymmetric profiled decking under varying load conditions.

Keywords: *Steel–Concrete Composite Floors, Profiled Steel Decking, Cross-Section Optimization, Flexural Stiffness, Moment of Inertia, Flange Width Ratio; Installation Stage, Service Stage, Live Load Influence, Fire Resistance.*

Introduction

Steel–concrete composite floor systems consisting of steel beams and monolithic reinforced concrete slabs cast on galvanized profiled steel decking are widely used in industrial, civil, and public buildings due to their high structural efficiency and construction speed. Numerous experimental and numerical studies confirm that the structural behavior of such floors strongly depends on the geometric characteristics of the profiled steel decking, including rib height, flange widths, and sheet thickness [1, 3, 6].

Finite element modeling has been extensively applied to analyse composite slabs with profiled steel decking, allowing detailed assessment of stress–strain behavior, stiffness, and ultimate capacity under monotonic loading [1,2,5]. Experimental investigations have also demonstrated that the geometry of the decking profile significantly influences flexural performance, shear bond characteristics, and failure modes of composite slabs [4, 6, 11].

Compared with traditional reinforced concrete slabs, composite floors allow reductions in slab thickness of up to 10% and total slab weight of 30–50%, while construction time may be shortened by approximately 25%. Furthermore, the profiled decking acts as both permanent formwork and external reinforcement, providing favorable conditions for integrating building services within the slab depth [1, 12].

Despite the extensive research on composite slabs, most commercially available profiled steel decking is produced with standardized geometries that are not optimized for different stages of

[1] Samarkand State University of Architecture and construction named after Mirzo Ulugbek.
[2] Samarkand State University of Architecture and construction named after Mirzo Ulugbek.
[3] Samarkand State University named after Sharof Rashidov Samarkand. Republic of Uzbekistan, Email: bakhriyev.nf@mail.ru

structural performance. In particular, the influence of the ratio between upper and lower flange widths on flexural stiffness during installation and on efficiency during the service stage remains insufficiently investigated [3, 7].

The objective of this study is to determine the optimal cross-sectional shape of profiled steel decking by analyzing the influence of flange width ratios and decking height on stiffness and load-bearing capacity at different stages of structural behavior.

Regulatory Background and Fire Design Considerations

The design of steel–concrete composite floors is regulated by international standards, primarily Eurocode 4, which establishes general rules for composite steel–concrete structures [8]. The behavior of profiled steel decking as a thin-walled cold-formed steel element is governed by Eurocode 3, Part 1.3, which provides supplementary rules for cold-formed members and sheeting [9, 13].

The fire resistance design of steel–concrete composite floors is governed by national and international standards, including:

- **SP 266.1325800.2016** – Design of steel–reinforced concrete structures
- **SP 468.1325800.2019** – Fire resistance of concrete and reinforced concrete structures
- **Federal Law No. 123** – Fire safety requirements for buildings (R15–R240)

Fire resistance of composite slabs with profiled steel decking is a critical design issue, as unprotected steel decking rapidly loses strength when exposed to elevated temperatures. Experimental and numerical studies show that the load-bearing capacity of composite slabs under fire conditions depends on the thermal response of the steel deck, concrete cracking, and membrane action effects [10]. Advanced fire design approaches increasingly consider membrane behaviour, which may significantly enhance fire resistance without increasing slab thickness or applying additional fire protection [10].

1. **Thermal analysis**, based on the standard fire curve

$$T=345\log_{10}(8t+1)+20, \qquad (1)$$

where t is the fire exposure time (min).

2. **Structural analysis**, accounting for the reduction of material strength at elevated temperatures.

For unprotected steel decking, loss of load-bearing capacity may occur within 15–30 minutes. Achieving fire resistance ratings of REI 60 or higher generally requires additional reinforcement within the slab ribs or application of fire-protective coatings. Recent design approaches (2025–2026) increasingly consider membrane action, which can significantly enhance fire resistance without increasing slab thickness.

Optimization at the Installation Stage

Problem Formulation

During the installation stage, prior to concrete hardening, the profiled steel decking acts as permanent formwork and carries the full construction load. At this stage, flexural stiffness is the governing parameter, as confirmed by experimental and numerical investigations of reinforced and unreinforced profiled decking [6, 14].

Previous analytical and numerical studies indicate that the moment of inertia of the decking cross-section plays a decisive role in limiting deflections and preventing local instability during concrete placement [1,5]. However, existing design recommendations do not explicitly address the optimization of flange width ratios.

During the installation stage, before the concrete gains sufficient strength, the profiled steel decking carries the full construction load. Its flexural stiffness is therefore a governing parameter. Let the wave length be b, the decking height h, and the sheet thickness δ. The ratio of the upper flange width b_t to the wave length is defined as:

$$k=b_t/b \qquad (2)$$

The cross-sectional area within one wave is:

$$A=\delta(b+2h) \quad (3)$$

The centered location and moment of inertia are derived analytically. Substitution leads to the following expression for the moment of inertia:

$$J=0.125b^3\delta(0.333+k-k2) \quad (4)$$

Optimal Flange Width Ratio

Analytical optimization of the cross-section shows that the maximum moment of inertia during the installation stage is achieved when the upper and lower flange widths are equal, resulting in a symmetric cross-section. This finding is consistent with classical structural mechanics principles and agrees with trends observed in experimental studies of flexural behaviour of profiled steel decking [6].

Similar conclusions regarding the influence of geometric symmetry on stiffness have been reported in numerical studies of profiled decking under construction-stage loading [3,5].

Differentiation with respect to *k* yields the maximum moment of inertia at:

k=0.5.

Thus, **maximum stiffness is achieved when the top and bottom flanges have equal widths**, i.e., when the cross-section is symmetric about the horizontal axis. This result is independent of the ratio *h/b* and is consistent with classical rolled steel sections (fig.1.).

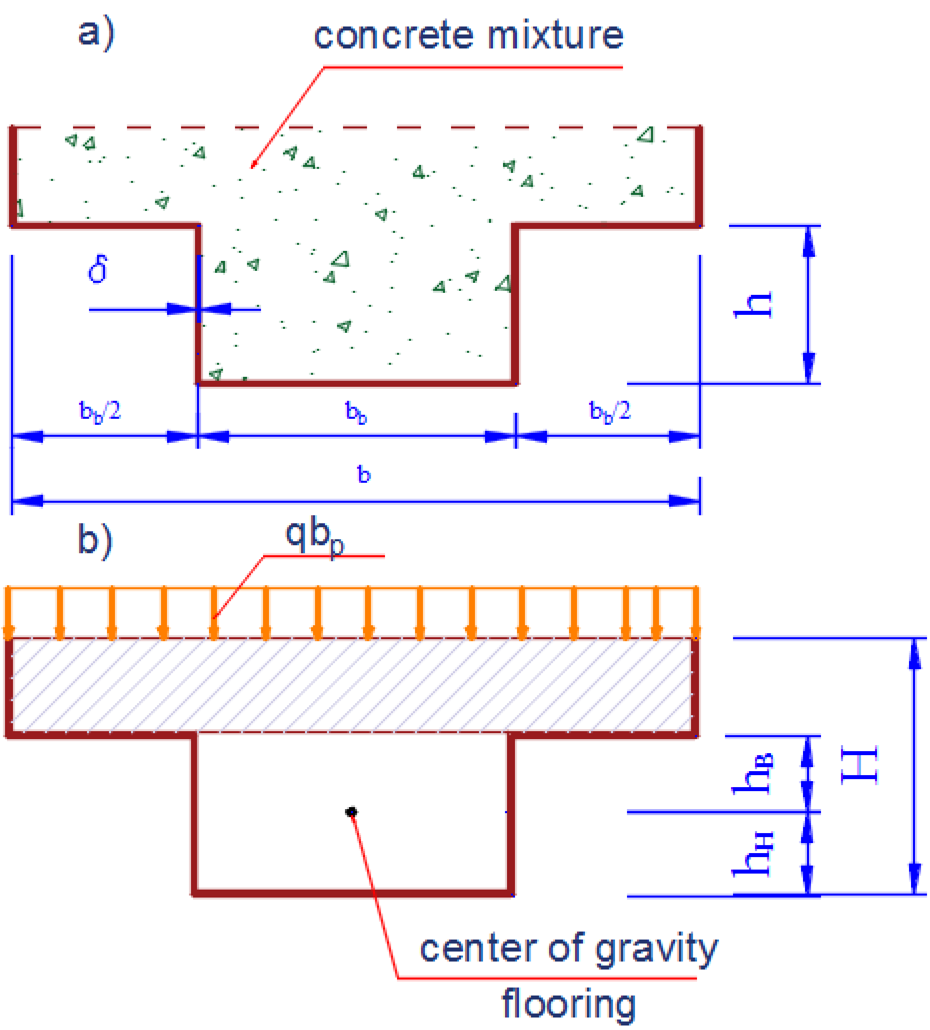

Fig. 1. Determination of the optimal shape of the decking cross-section: a — installation stage, b — service (operation) stage

Further optimization shows that, for a fixed amount of steel, an optimal ratio of decking height to thickness exists that maximizes the load-bearing capacity during concrete placement. Analytical evaluation yields an optimal value corresponding to:

$$\delta/h \approx 1.5 \quad (5)$$

Comparison with currently manufactured decking (δ/h = 2.1…4.45) indicates that many products are suboptimal for construction-stage performance.

Optimization at the Service Stage

Influence of Flange Width Ratio

During the operational stage, the profiled steel decking works compositely with the concrete slab. The effectiveness of composite action depends on the geometry of the decking profile, which affects the position of the neutral axis, the internal lever arm, and the amount of concrete in the tension zone [4,7].

Experimental studies demonstrate that increasing the bottom flange width enhances bending resistance but may simultaneously increase self-weight and reduce overall efficiency, particularly for slabs subjected to moderate live loads [4,6].

During the operational stage, the decking works compositely with concrete. For a fixed overall slab height *H*, redistribution of steel between the top and bottom flanges affects:

- the position of the neutral axis,
- the internal lever arm,
- the amount of concrete in tension (non-working zone).

Increasing the bottom flange width increases the effective lever arm and bending resistance but simultaneously increases the self-weight of tensioned concrete, reducing useful load capacity.

Objective Function

Recent numerical studies employing finite element analysis have successfully used optimization criteria based on cost-to-capacity or stiffness-to-weight ratios to determine optimal decking geometries [2]. Parametric analyses performed for different live load levels confirm that the optimal flange width ratio varies significantly depending on service load magnitude.

At low live loads, the optimal solution approaches a flat steel sheet located in the tension zone, whereas higher live loads require a wider bottom flange to maximize bending capacity and composite efficiency [2, 5].

An efficiency criterion is formulated as:

$$F = C / M_{eff} \quad (6)$$

where *C* is the total cost of steel and concrete, and M_{eff} is the effective bending moment considering self-weight effects.

Using realistic material costs, geometric parameters, and live loads (*p* = 200 and 400 kg/m²), parametric analysis is performed with respect to:

$$n = b_t / b \quad (7)$$

Results

- At **zero live load**, the optimal solution degenerates into a flat steel sheet located in the tension zone.
- At **moderate live loads (≈200 kg/m²)**, the optimal value is *n ≈ 0.33*, meaning the bottom flange should be narrower than the top flange.
- At **high live loads (≈400 kg/m²)**, the optimal configuration corresponds to *n → 0*, i.e., the bottom flange should be significantly wider than the top flange.

Practical Implications

The obtained results are consistent with previous experimental and numerical research, which highlights the importance of tailoring the decking geometry to specific load conditions rather than using a universal profile [3, 7]. Orientation of asymmetric decking profiles in accordance with the dominant loading scenario can significantly improve structural efficiency and economic performance of composite floor systems.

The results lead to the following practical recommendations:

- Asymmetric profiled decking should be **oriented differently depending on the live load**:
  - narrow flange downward for low live loads,
  - wide flange downward for high live loads.
- Composite floors designed for different load levels should employ **different decking profiles**, rather than a single universal geometry.
- Manufacturers should consider producing decking optimized separately for construction-stage stiffness and service-stage efficiency.

Conclusion

1. Maximum flexural stiffness of profiled steel decking during installation is achieved when the top and bottom flange widths are equal.
2. For a fixed steel quantity, an optimal ratio between decking height and wave length exists, maximizing load-bearing capacity during concrete placement.
3. In the operational stage, the optimal flange width ratio depends strongly on the live load magnitude.
4. Low live loads favor narrower bottom flanges, while high live loads require wider bottom flanges.
5. Rational orientation and selection of asymmetric decking profiles can significantly improve structural efficiency and economic performance of steel–concrete composite floors.

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