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Development of a computational tool for the structural analysis and design of composite steel-concrete slabs with steel decking

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Abstract. This contribution presents a web-based structural application for the design and verification of composite steel-concrete slabs, based on ultimate strength, stability, and serviceability limit state criteria. Its intuitive interface, accessible via browser on both desktop and mobile devices, enables engineers to efficiently perform structural calculations, including the determination of design actions and resisting capacities, as well as the verification of code-based requirements. In addition, the application specifies the required quantities of steel reinforcement for concrete shrinkage control and to provide additional strength in regions subject to negative moments. Optional verifications such as fire design are also available for the user. The application presented herein is structured into three core modules: a user interface (frontend), a data management layer (backend), and a processing module responsible for executing structural simulations. Once the input data is submitted, the backend processes the information and forwards the parameters to the analysis engine. Results are stored and presented to the user in a clear and organized format. The accuracy of the results has been validated against theoretical formulations and recent updated design standards, including ABNT NBR 8800:2024, AISI S100:2024, and ABNT NBR 14323:2013. The results obtained confirm the tool's applicability to practical structural design scenarios. This solution contributes to the modernization of composite slab design in civil engineering, enhancing calculation efficiency, precision, and structural analysis automation.

Keywords: Composite slabs, Steel deck, SLS design, ULS design, Computational tool.

1 Introduction

The use of composite slabs with steel decking represents an efficient and versatile solution in modern construction [1]. leveraging the steel-concrete combination to optimize structural performance. This system integrates the deck as permanent formwork into the final structure (Fig. 1), offering significant advantages over conventional construction such as reduced shoring.

To facilitate analysis and design, a specialized web application was developed to evaluate structural behavior

across different phases. Various studies have contributed to validating design methodologies through experimental and numerical approaches, covering both the initial stage where the deck acts independently [2][3] and the service stage with composite action. These studies assess the performance of both the isolated profile and the composite element, frequently investigating longitudinal shear failure through push-out tests [4][5][6], flexural tests [7][8][9], or numerical simulations [10][11][12][13].

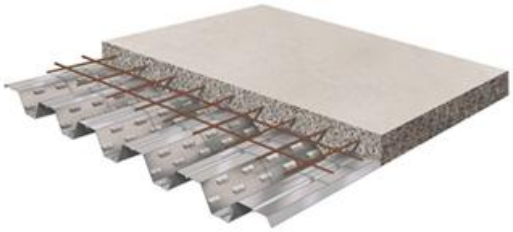


Figure 1. Composite Slab Representation: Polydeck 59S Steel Deck Overview [14].

Traditional CAE software has historically been developed as desktop programs. However, this approach contrasts with current trends in the global computing market, where models like Hardware-as-a-Service (HaaS), Platform-as-a-Service (PaaS), and Software-as-a-Service (SaaS) are rapidly gaining traction. Today, routine tasks such as email management, text editing, spreadsheet processing, and presentation design are efficiently handled through web applications, progressively replacing desktop equivalents.

This paper presents a fully functional Structural Software-as-a-Service (SSaaS) web application for analyzing the composite slabs described previously. The tool performs verifications both before and after concrete curing, including fire scenario evaluations, and analyses of configurations with one, two, or three spans. The SSaaS approach provides industry and researchers with access to state-of-the-art structural analysis tools. These platform-independent solutions remain continuously updated and globally accessible, enabling collaborative work and driving innovation in the field.

2 Software Architecture

Key defining characteristics of SaaS include web-based access to commercial software, centralized software management, a "one-to-many" delivery model, and automated handling of updates and patches. Like traditional client-server applications, SaaS consists of three core components: a client application for data input, a server application that processes the analysis, and a client-server communication protocol governing their interaction.

The interaction and workflow of the proposed analysis tool follow two main steps as shown in Fig. 3. First, the client-side web browser sends an initial request to access the application, which travels through the network to the main web server. The server responds by sending the essential interface files (JavaScript, CSS, and HTML) that the browser loads to display the user interface.

For the analysis phase, the user inputs structural analysis parameters which are packaged into a JSON object and sent to the server via POST request. The Django-based web server (with PostgreSQL for databases) processes the request through a synchronous process that includes data validation, relational database storage, structural calculations execution, and report generation.

3 Verification Before Curing

Before concrete curing, composite slabs require a series of important verifications focused on the performance of the metal deck. In this stage, the deck not only acts as a permanent formwork for the concrete but also plays a fundamental structural role by supporting temporary construction loads, such as the weight of fresh concrete, live loads from workers and equipment, in addition to concrete accumulation or material concentration. These verifications include evaluating the deck's resistance to various stresses.

The flexural moment verification is performed according to the AISI S100:2024 standard [15] using the Direct Strength Method (DSM), developed by Schafer & Peköz [16] This method determines the nominal strength

(M_n) by considering lateral-torsional, local, and distortional buckling modes, based on their respective elastic critical moments. For vertical shear strength, the AISI S100:2024 [15] standard provides a procedure to calculate the nominal strength (V_n) based on the shear yield strength (V_y) and the shear buckling strength (V_{cr}), taking into account the web slenderness (λ_v). The nominal web crippling strength (Pn) is calculated using an empirical equation from the AISI S100:2024 standard [15], which considers the steel thickness, bearing length, and section geometry, following the loads defined in ANSI/SDI SD-2022 [17].

Finally, for the Serviceability Limit State, the maximum deck deflection under the fresh concrete weight must not exceed L/180 or 20 mm, as per NBR 8800:2024 [18]. If the deflection exceeds L/250, a 70% increase in the concrete thickness must be considered to account for the ponding effect.

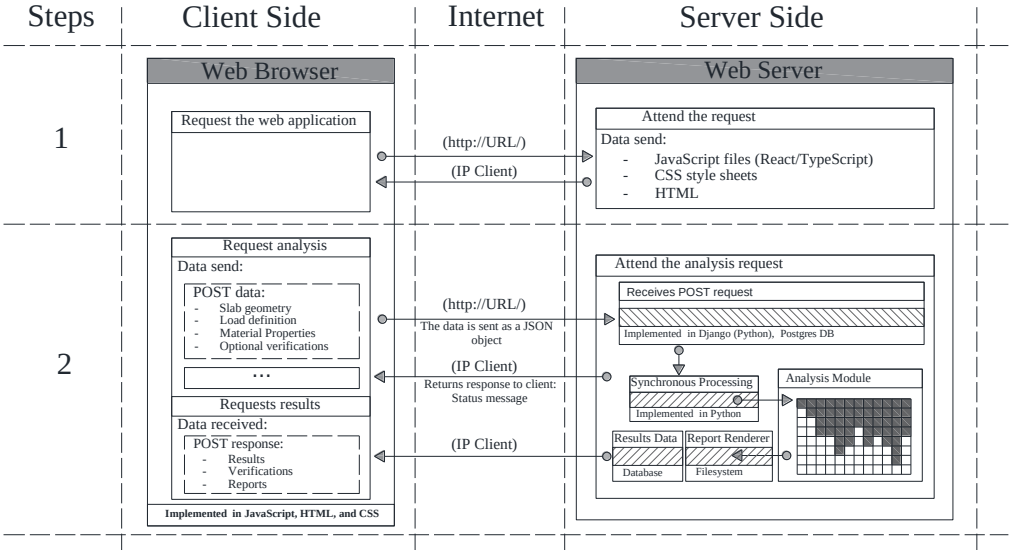


Figure 2. System Workflow Diagram

4 Verifications after Curing

Once the concrete has cured, the slab functions as a fully composite element where the steel and concrete work together to resist service loads. At this stage, the composite slab must verify its structural capacity under permanent and variable loads.

The complete interaction between steel and concrete must be verified using the m-k method from NBR 8800:2024 [18]. This empirical method determines the longitudinal shear strength based on experimentally obtained constants (m, k) obtained through tests performed according to EN1994-1-1 [19] and the effective area of the deck. For the Polydeck 59S deck, the coefficients from Mello [13] (m = 91.22 N/mm², k = 0.043 N/mm²) are used, derived from numerical simulation which provides conservative results. The positive moment calculation is based on the location of the plastic neutral axis. This is determined by comparing the compressive force of the concrete (N_{cf}) with the tensile force of the deck (N_{pa}). When $N_{cf} \geq N_{pa}$, the plastic neutral axis is located in the concrete cover (in Fig. 3a), a common scenario due to the minimum cover thickness of 50 mm required by EN 1994-1-1 [20]. The flexural strength (M_{Rd}) is then calculated considering the moment equilibrium in the section.

In continuous slabs, the negative moment resistance at intermediate supports is calculated considering only the top tensile reinforcement and the compressed concrete, disregarding the contribution of the compressed deck. The negative reinforcement area (A_s^-) (in Fig. 3b), must comply with NBR 6118:2023[21]. The calculation considers an effective width (b_{ef}) based on the rib geometry. The total vertical shear strength ($V_{v,Rd}$) combines the contribution of the deck ($V_{v,F,Rd}$, calculated according to AISI S100:2024 [15]) and the concrete web ($V_{v,c,Rd}$). The concrete contribution depends on its tensile strength, the longitudinal reinforcement ratio, and a size factor (k_v), with a limit value (V_{max}) that cannot be exceeded. In service conditions, the vertical deflection of the composite slab must be verified not to exceed $L_f/350$ under variable loads, according to NBR 8800:2024[18]. This verification ensures user comfort and the proper performance of non-structural elements.

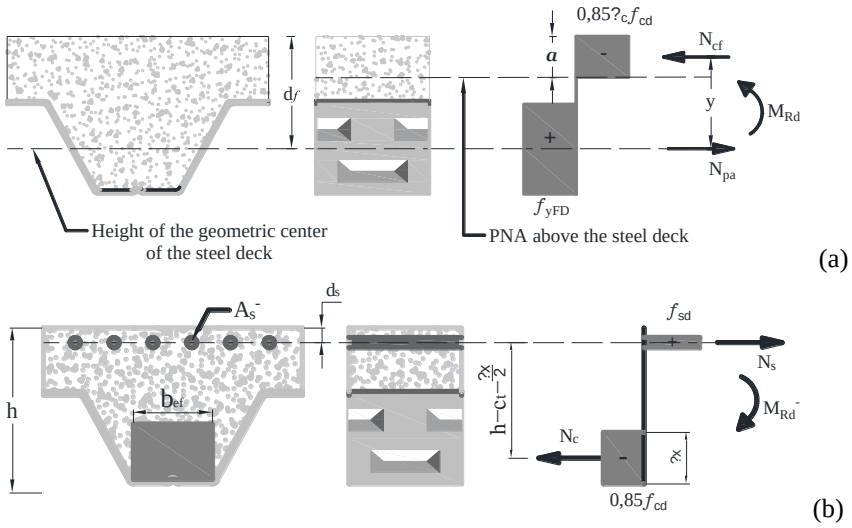


Figure 3. Stress diagram for positive (a) and negative (b) moment with plastic neutral axis above the steel deck[21]

5 Fire Resistance Verification

The fire resistance verification, according to Brazilian standards NBR 13860 [22] and NBR 14432 [23], ensures the composite slab maintains its structural function during the Required Fire Resistance Time (TRRF). The slab must meet three criteria: integrity, thermal insulation, and structural stability. Thermal insulation is verified by ensuring the slab's effective thickness (h_{ef}) exceeds a minimum value based on the TRRF.

Structural stability is assessed by checking the flexural strength under fire conditions. For positive bending moment, the resistance ($M_{fi,Rd}^{+}$) is calculated considering the thermal degradation of steel and concrete using reduction factors ($k_{s,\theta}$, $k_{c,\theta}$). The reinforcement temperature (θ_s) is estimated with an empirical formula that accounts for the slab's geometry. For negative bending moment, the resistance ($M_{fi,Rd}^{-}$) is calculated considering the top reinforcement at ambient temperature and the compressed concrete affected by heat, with a compressed region defined by the θ_{lim} isotherm.

6 Practical Example

This section describes the typical two-span slab configuration used to validate the computational tool, representing a standard solution in continuous composite slab construction. The slab rests on secondary beams with a typical span of 2.6 m, selected because spacings under 3.0 m [24], generally don't require shoring during pouring, making the construction stage critical where the deck must independently support temporary loads.

Before curing, the deck acts as a continuous element and must resist negative moments at intermediate supports. After curing, although physical continuity exists, it's typically not considered in design unless explicitly intended. The application calculates negative moment resistance under both conditions, initially considering the welded wire mesh (WWM) and automatically adding supplemental reinforcement when needed.

The concrete cover thickness must not be less than 50 mm, as stipulated by EN 1994-1-1 (2024)[20], while the total slab depth (adopted as 130 mm for validation) depends on the span between supports and service loads. The actions considered in the design include permanent loads and live loads, selected to maximize the structural utilization of the slab in the final verification stage.

7 Results

The computational tool automates the exploration of load positions on the slab to identify the most unfavorable configuration that produces maximum internal forces. All results are calculated and presented per unit

width. The system systematically evaluates different loading configurations, selects the extreme structural response values, and uses them in strength and serviceability verifications, ensuring all critical design conditions are considered.

Table 1. Design Load Values and Partial Factors for ULS, SLS and Fire Design

Load	Type	Characteristic Value (kN/m^2)	ULS			SLS
			Load Factor Construction Load Combinations	Load Factor Normal Load Combinations	Load Factors for Fire Design	Load Factors
Self-weight of fresh concrete	Variable / Main	2.378	1.25	–	–	1.0
Self-weight of concrete	Permanent	2.378	–	1.40	1.0	1.0
Self-weight of steel deck	Permanent	0.0814	1.15	1.25	1.0	1.0
Construction live load	Variable / Secondary	1.00	1.3 × 0.8	–	–	1.0
Live Load	Variable	5.50	–	1.5	0.21	1.0

The tool automatically generates load combinations according to the limit states of NBR 8800:2024, applying the corresponding factors to characteristic loads. These combinations cover all relevant design situations, including: the construction stage, normal situation combinations, fire design, and serviceability limit states. Table 1 systematically consolidates these combinations for both critical design stages.

VERIFICATIONS BEFORE CONCRETE CURING

Verification for Positive Flexure (ULS)

Maximum Positive Design Moments: $M_{Sd}{}^{+} = 2.66\ [kN\ m/m]$

Positive Design Moment Resistance: $M_{Rd}{}^{+} = 4.86\ [kN\ m/m]$

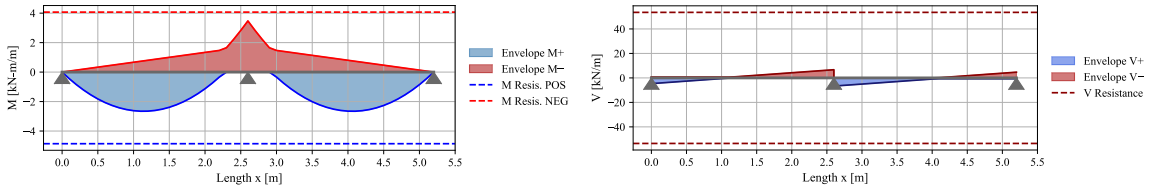
Efficiency 54.70%

Verification for Negative Flexure (ULS)

Maximum Negative Design Moments: $M_{Sd}{}^{-} = -3.47\ [kN\ m\ /m]$

Negative Design Moment Resistance: $M_{Rd}{}^{-} = -4.07\ [kN\ m/m]$

Efficiency 85.31%



Verification for Shear (ULS)

Maximum Design Shear Force: $V_{Sd} = 6.68\ [kN\ /m]$

Design Shear Resistance: $V_{Rd} = 54.00\ [kN\ /m]$

Efficiency 13.4%

Web Crippling Verification (ULS)

Maximum Design Reactions:

$F_{\ Sd_ext1} = 4.59\ kN/m\ ;\ F_{\ Sd_{int1}} = 10.19\ kN/m$

$F_{\ Sd_ext2} = 3.34\ kN/m\ ;\ F_{\ Sd_{int2}} = 11.12\ kN/m$

Design Reaction Resistance:

$F_{\ Rd_ext1} = 5.09\ kN/m\ ;\ F_{\ Rd_{int1}} = 18.70\ kN/m$

$F_{\ Rd_ext2} = 5.36\ kN/m\ ;\ F_{\ Rd_{int2}} = 18.27\ kN/m$

Efficiency 90.17%

Deflection Verification (SLS)

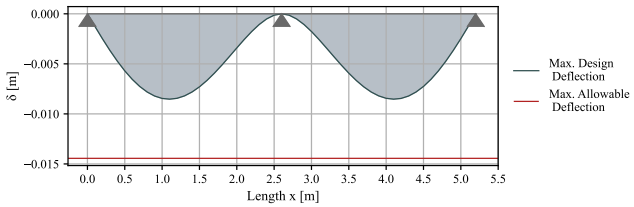
Maximum Design Deflection:

$\delta_{Sd} = -8.53\ mm$

Maximum Allowable Deflection:

$\delta_{Rd} = -14.44\ mm$

Efficiency 59.08%



VERIFICATIONS BEFORE CONCRETE CURING

Verification for Positive Flexure (ULS)

Maximum Positive Design Moments:

$M_{Sd}{}^{+} = 6.88\ [kN\ m/m]$

Positive Design Moment Resistance:

$M_{Rd}{}^{+} = 24.46\ [kN\ m/m]$

Efficiency 28.13%

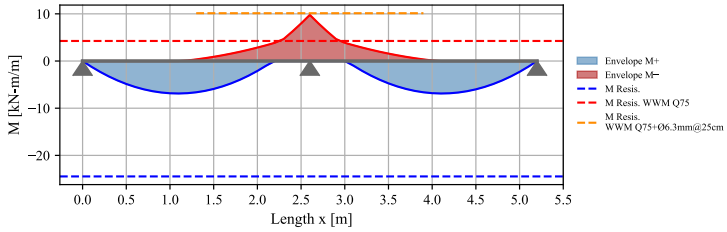
Verification for Negative Flexure (ULS)

Maximum Negative Design Moments: $M_{Sd}{}^{-} = -9.77\ [kN\ m\ /m]$

Negative Design Moment Resis. with Welded Wire Mesh (Q75): $M_{Rd}{}^{-} = -4.07\ [kN\ m/m]$

Negative Design Moment Resis. with WWM + Ø16 bars @ 1.0 m: $M_{Rd}{}^{-} = -10.13\ [kN\ m/m]$

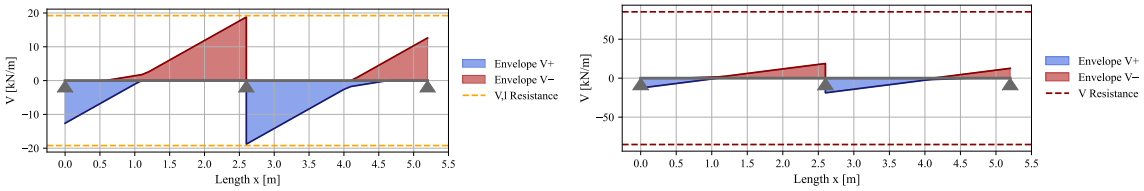
Efficiency 96.45%



Verification for Shear (ULS)

Maximum Design Shear Force: $V_{Sd} = 18.79\ [kN\ /m]$ Design Shear Resistance: $V_{Rd} = 85.12\ [kN\ /m]$

Efficiency 22.07%



Longitudinal Shear Verification

Design Shear Force associated with Longitudinal Shear:

$$V_{\ell,Sd} = 18{,}79\ [kN\ /m]$$

Design Shear Resistance associated with Longitudinal Shear:

$$V_{\ell,Rd} = 19{,}22\ [kN\ /m]$$

Efficiency 97.76%

Deflection Verification (SLS)

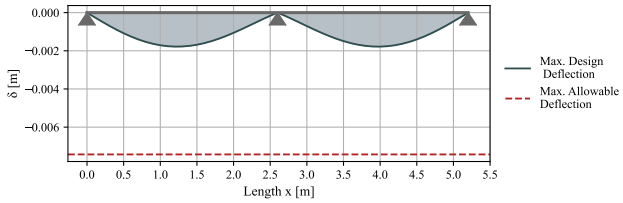
Maximum Design Deflection:

$$\delta_{Sd} = -1.78\ mm$$

Maximum Allowable Deflection:

$$\delta_{Rd} = -7{,}43\ mm$$

Efficiency 23.96%



FIRE DESIGN VERIFICATION

Integrity Requirement satisfied by the presence of the steel deck.

Thermal Insulation: $h_{ef} > h_{ef,min}$

Meets the thermal insulation requirement.

Stability

Max. Pos. Design Moments: $M_{fi,Sd}{}^{+} = 40.05\ [kN\ cm/Rib]$

Positive Design Moment Resistance:

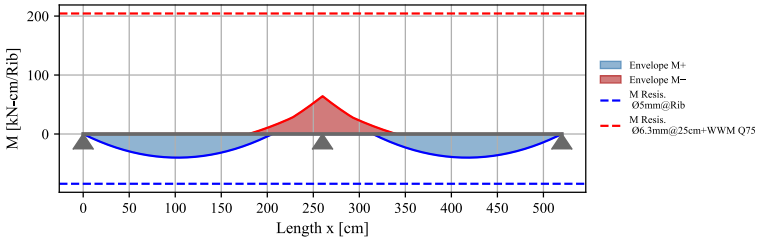
With Ø5mm@Rib: $M_{fi,Rd}{}^{+} = 84.41\ [kN\ cm/Rib]$

Efficiency 47.45%

Max. Neg. Design Moments: $M_{fi,Sd}{}^{-} = -64.18\ [kN\ cm/Rib]$

Negative Design Moment Resistance with WWM Q75+ Ø6.3mm bars @ 25cm: $M_{fi,Rd}{}^{-} = -204.37\ [kN\ cm/Rib]$

Efficiency 31.41%



8 Conclusions

The development of this web application for the analysis of composite steel-concrete slabs represents a significant contribution to structural engineering. Developed under the SSaaS model, the tool optimizes structural verification processes by providing an accessible and efficient environment for designing composite slabs across all phases, including fire scenarios and configurations of up to three spans. Validation through a practical example confirmed that the calculation procedures align with established normative criteria. Its accessibility, regulatory compliance, and continuous update capability make it a flexible alternative for current and future structural design demands, effectively integrating engineering knowledge with technological development.

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References

[1] P. . Don Allen, "History of Cold Formed Steel," no. November, pp. 28–32, 2006.

[2] W. Costa, V. Casioca, S. Chambilla, D. Fernandes, and H. Cardoso, "Resistência à flexão de uma fôrma metálica para laje mista : estudos experimentais e numéricos," *CBPE XVI Congr. Bras. Pontes e Estructuras*, 2023.

[3] W. Costa, "Resistência à flexão de uma fôrma metálica para laje mist," Dissertação de Mestrado em Andamento. Programa de Pós-graduação em Estruturas e Construção Civil (PECC). Universidade de Brasília (UnB).

[4] D. Lima e Silva, "Estudo experimental e numérico da resistência ao cisalhamento longitudinal na interface fôrma-concreto em lajes mistas com fôrma de aço incorporada: ensaios de push-out," Dissertação de Mestrado. Programa de Pós-graduação em Estruturas e Construção Civil (PECC). Universidade de Brasília (UnB).

[5] D. Silva, S. Gonçalves, G. Araújo, H. de S. Cardoso, G. Alencar, and R. de M. Lameiras, "Modelagem computacional de ensaios do tipo push-out em lajes mistas com forma metálica incorporada," *CBEM24 - Congr. Bras. Estruturas Mistas*, no. May, 2024.

[6] D. Silva *et al.*, "Development and Validation of a New Cost-Effective Test Method for the Assessment of Longitudinal Shear Failure in Composite Steel–Concrete Slabs," *Eng. Struct.*, no. (Under Review), 2024.

[7] M. Crisinel and F. Marimon, "A new simplified method for the design of composite slabs," *J. Constr. Steel Res.*, vol. 60, no. 3–5, pp. 481–491, 2004, doi: 10.1016/S0143-974X(03)00125-1.

[8] H. Y. Kim and Y. J. Jeong, "Ultimate strength of a steel-concrete composite bridge deck slab with profiled sheeting," *Eng. Struct.*, vol. 32, no. 2, pp. 534–546, 2010, doi: 10.1016/j.engstruct.2009.10.014.

[9] M. Soltanalipour *et al.*, "Shear transfer behavior in composite slabs under 4-point standard and uniform-load tests," *J. Constr. Steel Res.*, vol. 164, 2020, doi: https://doi.org/10.1016/j.jcsr.2019.105774.

[10] A. Plans, D. Grau, M. Soltanalipour, M. Ferrer-Ballester, F. Marimon, and A. Andreu, "Three-dimensional finite element modeling for bending and pull-out tests of composite slabs," *Eng. Struct.*, vol. 295, no. December 2022, p. 116785, 2023, doi: 10.1016/j.engstruct.2023.116785.

[11] J. Mello *et al.*, "Longitudinal shear strength design of composite slabs by full-scale FE modelling considering the embossments," *IBRACON Estruturas e Mater.*, vol. 17, no. 5, pp. 1–20, 2024, doi: 10.1590/s1983-41952024000500005.

[12] J. Mello, G. Alencar, and H. Cardoso, "Avaliação da Resistência de Lajes Mistas com Fôrma de Aço Incorporada por Meio do Método Dos Elementos Finitos," 2023, *CBPE-Congreso Brasileiro de Pontes e Estructuras 2023, Rio de Janeiro*.

[13] J. Mello, "Avaliação da Resistência de Lajes Mistas com Fôrma de Aço Incorporada por Modelagem em Elementos Finitos Considerando a Geometria das Mossas," Dissertação de Mestrado. Programa de Pós-graduação em Estruturas e Construção Civil (PECC). Universidade de Brasília (UnB)., 2023.

[14] O. S. Deck and O. S. Deck, "Polydeck 59S ®".

[15] ANSI/SDI AISI S100-2024, "American National Standards Institute / Steel Deck Institute," 2024.

[16] B. W. Schafer and T. Peköz, "Direct Strength Prediction of Cold-Formed Steel Members using Numerical Elastic Buckling Solutions," in *Fourteenth International Specialty Conference on Cold-Formed Steel Structures*, St. Louis, Missouri, 1998.

[17] ANSI/SDI SD-2022, "Standard for Steel Deck - Steel Deck Institute," 2022.

[18] ABNT NBR 8800:2024, "Projeto de estruturas de aço e de estruturas mistas de aço e concreto de edificações," 2024, *Associação Brasileira de Normas Técnicas*.

[19] EN 1994-1-1:2004, "Eurocode 4: Design of composite steel and concrete structures - Part 1-1: General rules and rules for buildings," vol. 1, 2004.

[20] prEN 1994-1-1:2024, "Eurocode 4 — Design of composite steel and concrete structures — Part 1-1: General rules and rules for buildings," 2024.

[21] ABNT NBR 6118:2023, "Projeto de estruturas de concreto," 2023, *Associação Brasileira de Normas Técnicas*.

[22] ABNT NBR 13860:1997, "Glossário de termos relacionados com a segurança contra incêndio," 1997, *Associação Brasileira de Normas Técnicas*.

[23] ABNT NBR 14432:2001, "Exigências de resistência ao fogo de elementos construtivos de edificações - Procedimento," 20011, *Associação Brasileira de Normas Técnicas*.

[24] "Edifícios de Pequeno Porte Estruturados em Aço," 2018.