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Load-bearing capacity and deformability of steel-concrete floors on profiled steel decking

Abstract. This article aimed to provide a regulatory and analytical justification of the effect of the degree of shear interaction on compliance with the requirements of the first and second groups of limit states for composite floors with profiled decking. The research was carried out on the basis of a regulatory and analytical approach and was implemented with the application of the current Ukrainian normative documents and codified calculation models of steel-concrete floors as composite flexural members. In the calculation models adopted, either full or partial compatibility of the strains of steel and concrete elements' deformations was adopted. The results showed that the load-bearing capacity and deformability of floors were interdependent properties formed within the framework of a unified stiffness-force mechanism of composite cross-section behaviour. It has been established that the degree of shear interaction between the steel deck and the concrete slab was an integrating parameter that simultaneously controlled the achieved design bending resistance and the effective stiffness of the floor system. With full shear interaction, the maximum realisation of the transformed geometrical and stiffness characteristics of the cross-section was achieved, which allowed fulfilling both groups of limit states simultaneously. In the case of partial composite action, a coordinated reduction in design resistance and an increase in deflections were observed, with deformability indicators showing greater sensitivity to reductions in effective stiffness than load-bearing capacity indicators. It was shown that, under identical service loads, deflections may reach permissible limit values earlier than limiting stresses were attained, thereby defining serviceability as the governing constraint in design decisions. The practical significance of the obtained results lies in the possibility of their application by design and expert organisations in the practice of regulatory assessment and design of steel-concrete floors with profiled decking

Keywords: composite action; shear interaction; serviceability; effective stiffness; deflections; limit states

INTRODUCTION

In modern building structures design practice, steel-concrete floors reinforced with a profiled steel decking were widely used. This was due to the features of their structural scheme, a rational balance between material consumption and the load-bearing capacity, as well as the ability to cover large spans with a given self-weight. Such floors were used both in civil and industrial construction as load-bearing and enclosing structural elements, and as participants in the spatial work of buildings. Within the current

regulatory framework, a key task was the assessment of the load-bearing capacity and deformability of composite floors with appropriate consideration of the composite action of the steel and concrete components, as the nature of this interaction governs the formation of the stress-strain state of the element. In the study by Y. Dmytrenko (2021), it was shown that code-consistent modelling of shear interaction between steel elements and the reinforced concrete slab had a direct effect on the determination of the

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effective geometric properties of the composite cross-section and the accuracy of its load-bearing capacity assessment. Even in the framework of linear elastic calculation models, the results were dependent on the accepted hypothesis about the level of composite action. The comprehensive approach to taking into account the stage-by-stage nature of structures' behaviour was realised in the study by M. Savytskyi *et al.* (2021), which stated that the stress-strain state of the steel-reinforced concrete floors changed essentially depending on the construction stage. This finding substantiated the need for a normative distinction between design situations and for separate verifications with respect to limit states. The study also demonstrated the transition from the behaviour of steel elements acting without participation of the concrete slab to the formation of full composite action, accompanied by changes in the distribution of internal forces and deflections. In the study by A. Hasenko *et al.* (2022), the influence of effective geometric parameters of the composite cross-section on the load-bearing capacity of floors was analysed. It was shown that a reduction in the effective width of the concrete slab or a decrease in the efficiency of shear interaction was accompanied by a reduction in the flexural strength of steel-reinforced concrete systems. Within that study, the relationship between the parameters of the composite cross-section, load-bearing capacity, and deformability of floors was examined. The study by L. Storozhenko & G. Gasii (2020) systematised design aspects of the calculation of steel-concrete floors, with particular emphasis on the consideration of deflections, crack resistance, and the composite action of materials within the national regulatory framework. It was shown that rational use of composite elements enabled a reduction in material consumption, provided that checks for the first and second groups of limit states were performed correctly.

In the research by M. Hernich *et al.* (2021), steel-reinforced concrete structural systems were treated as a single composite cross-section, for which the stress-strain state and deformability were analysed with due regard to the mechanical properties of the materials and the conditions of shear interaction. Using the example of bridge superstructures, it was substantiated that such a composite scheme provided increased stiffness and load-bearing capacity, while simultaneously reducing mass, which was of particular importance for tasks related to the restoration of transport infrastructure. A publication by M. Saccone *et al.* (2025) summarised the results of experimental and theoretical investigations of composite floors, which indicated the influence of longitudinal shear behaviour on the formation of the ultimate load-bearing capacity and the serviceability deformation capacity for various concretes. It was noted that the characteristics of the "deck-slab" interaction affect the actual parameters of the composite action and the values of the calculated deflections. Similar results were obtained in the study by P. Ravichandran & S. Harini (2024), where it was shown that the design span, the geometrical parameters of the profiled deck and the

thickness of the concrete layer affected the stiffness of the composite cross-section, due to the influence on the effective moment of inertia and the values of deflections. This fact necessitated their normatively consistent accounting in the design evaluation of the deformability of steel-concrete floors. In the study by L.G.F. Grossi *et al.* (2020), the behaviour of composite slabs with profiled steel decking was analysed through the mechanism of longitudinal shear at the "deck-concrete" interface as a factor determining the degree of composite action and the governing type of limit state. Experimental comparison of specimens with different shear span lengths and additional reinforcement showed that the introduction of reinforcing bars increased the realised shear load-bearing capacity and shifts slab behaviour towards a more stable and deformable response compared with unreinforced solutions. The results obtained were interpreted in terms of evaluating longitudinal shear strength as a parameter that determined the degree of involvement of the steel component in the work and the limits of applicability of structural solutions for composite floors. In the research by B.A. Izzuddin & J. Sio (2021), the floor was recognised as the main element of frame structures that provided force redistribution and structural integrity under accidental actions. The authors argued that the deformative properties of floors should be taken into account, when analysing robustness, since horizontal tie forces, which were decisive for excluding the progressive collapse of structures, were transmitted precisely through the floor slabs.

Despite the presence of scientific and applied research in the scientific and technical literature, there were various approaches to the theoretical evaluation of the load-bearing capacity and deformability of steel-concrete floors with profiled steel decking, which have not been systematised in the form of a single normatively consistent design calculation scheme. The publications differed in the methods for consistently taking into account the effect of partial shear interaction, determining the actual geometrical parameters of the composite cross-section, as well as combining the verification of the first and second groups of limit states without using empirical coefficients. In addition, there were differences in understanding the content of the relationship between the loadbearing capacity and the serviceability-related deformability in the current normative documents. This study aimed to perform a theoretical estimation of the load-bearing capacity and deformability of the steel-concrete floors reinforced with profiled steel decking, taking into account the interrelated requirements of the first and second groups of limit states and the composite action of the steel and concrete elements. To achieve the stated aim, the study performed a regulatory and analytical estimation of the load-bearing capacity of the steel-concrete floors reinforced with profiled steel decking according to the first group of limit states, taking into account the geometric parameters of the composite cross-section and the conditions of shear interaction. The influence of the degree of shear interaction between the



steel and concrete on the composite action of the floor system and the effective stiffness characteristics of the cross-section was analysed. A theoretical estimation of the floor deformability according to the second group of limit states was also carried out, and an integrated normative interpretation of the relationship between the load-bearing capacity and serviceability was provided.

MATERIALS AND METHODS

The study was performed as a regulatory and analytical investigation, focused on a reproducible interpretation of design verifications for the steel-concrete floors reinforced with profiled steel decking within the framework of the limit state method. The source base consisted of current regulatory and regulatory-technical documents of Ukraine, which were applied in accordance with their functional purpose for the specification of loads and load combinations, verification of the steel and concrete components, consideration of composite action, and serviceability criteria. The permanent and variable loads, as well as the design load combinations, were established in accordance with SCN No. V.1.2-2:2006 (2006). Requirements for the steel elements of the floor system, in particular for the profiled decking as the steel component of the composite cross-section, were applied in accordance with SCN No. V.2.6-198:2014 (2022). The design properties of concrete and the principles for assessing the resistance of concrete and reinforced concrete elements were adopted in accordance with SCN No. V.2.6-98:2009 (2009). Checks for the first and second groups of limit states, including criteria for load-bearing capacity and serviceability, were interpreted in accordance with SCN No. V.1.2-6:2021 (2022). The consideration of the composite action of the steel and concrete was implemented through the code-defined concept of the degree of shear interaction between the profiled decking and the concrete slab. The general principles for the analysis and design of steel-reinforced concrete elements, together with terminological approaches, were adopted in accordance with SCN No. V.2.6-160:2010 (2010). Provisions relating to the parameters of composite action, effective geometric and stiffness characteristics of the composite cross-section, and conditions of partial shear interaction were taken from the DSTU No. B V.2.6-215:2016 (2016).

The methodology was based on a sequential analysis, harmonisation, and systematisation of regulatory requirements, followed by the structured presentation of conclusions for the first group of limit states (ultimate limit state, ULS) and the second group of limit states (serviceability limit state, SLS). At the first stage, requirements for the specification of loads and load combinations were organised, and ULS criteria were generalised in the form of a normative condition ensuring loadbearing capacity, while SLS criteria were formulated in terms of deformation (deflection) limits as a component of serviceability. At the second stage, provisions concerning the composite action of steel and concrete were systematised, with explicit distinction between conditions of full and partial shear interaction

as prerequisites determining the effective characteristics of the composite cross-section applied in ULS/SLS verifications. At the third stage, the factors influencing compliance with the requirements of the first group of limit states were presented in a reproducible format of “parameter – normative condition – engineering interpretation of influence”. Within this framework, the following parameters were identified: concrete slab thickness, geometry of the profiled decking, degree of shear interaction, composite action scheme, and level of design loading. The synthesis of the results was formulated as a normatively consistent theoretical interpretation of the relationship between load-bearing capacity and deformability, considered as interrelated characteristics of the behaviour of steel-concrete floors within building load-bearing systems.

RESULTS

Load-bearing capacity of steel-concrete floors according to the first group of limit states

Analysis of the results of the regulatory and analytical assessment of the load-bearing capacity of steel-concrete floors according to the first group of limit states showed that fulfilment of the condition $M_{Ed} \leq M_{Rd}$, derived from the normative criterion for ensuring load-bearing capacity under the first group of limit states in accordance with SCN No. V.1.2-6:2021 (2022) is governed by a set of interrelated structural and regulatory factors. This list included: the design values and combinations of external loads; geometrical parameters of the composite cross-section (the thickness of the concrete slab, the geometrical parameters of the profiled decking, and the position of the neutral axis); design parameters of the steel and concrete; conditions for the implementation of the composite action, which was the degree of shear interaction between the profiled decking and the concrete slab. All these factors together determined the relation between the design effect and the design resistance of the cross-section. In the framework of the existing normative approach, the load-bearing capacity of the floor was considered not as the sum of the resistances of the individual components of the structure, but as an integral property of the steel-concrete cross-section, formed according to the principles of the composite action. The rational choice of the above parameters made it possible to use the profiled steel decking not only as permanent formwork, but also to involve it in the process of resisting bending loads, which increased the effective resistance of the cross-section and reduces the level of stresses in the concrete component. Such behaviour of the floor corresponded to the normative concept of steel-concrete systems as single composite elements (according to SCN No. V.2.6-160:2010, 2010), in which the distribution of internal forces between the interacting materials was determined not by their nominal properties, but by their composite action in the composite cross-section. It was in these conditions that the fulfilment of the requirements of the first group of limit states was ensured, without artificially increasing the cross-sections or introducing additional structural reserves.





The results showed that the normatively admissible level of resistance of the composite cross-section was formed depending on the geometrical parameters of the floor system, in particular, the relation between the height of the profiled steel decking and the thickness of the concrete layer, and the position of the neutral axis in the flexural cross-section. In particular, the reduction of the thickness of the concrete slab or the efficiency of shear interaction between the steel decking and the concrete led to a decrease in the design resistance of the composite cross-section, which was observed in the results of verification of the conditions of the first group of limit states. Within the requirements of the SCN No. V.1.2-6:2021 (2022), it manifested itself in a decrease in the design resistance M_{Rd} and, consequently, in a narrowing of the range of permissible design solutions, even in the case of meeting the standard values of loads and impacts specified in SCN No. V.1.2-2:2006 (2006). Under these conditions, the reserve of the load-bearing capacity of the floor was limited, and full composite action was not realised, which indicated the fundamental importance of the structural compatibility

of the floor components within the normative calculation model. The formation of the load-bearing capacity of steel-concrete floors was directly related to the conditions of shear interaction between the profiled steel decking and the concrete slab. In accordance with the provisions of SCN No. V.2.6-160:2010 (2010) and DSTU No. B V.2.6-215:2016 (2016), the level of shear interaction was used to classify the modes of behaviour of the steel-concrete cross-section with full or partial compatibility of deformations. A decrease in the efficiency of shear interaction led to a redistribution of the internal forces in the cross-section, an increase in the share of the bending stresses perceived by the concrete component and a decrease in the reduced design resistance of the steel part. In a normative sense, this was manifested in a decrease in M_{Rd} and, as a consequence, a further narrowing of the range of admissible design solutions within the first group of limit states. In order to systematise the effect of the main parameters on fulfilment of the criteria for the first group of limit states, the normative dependencies were systematised in the form “parameter – normative condition – and effect” (Table 1).

Table 1. Systematisation of normative parameters influencing fulfilment of the $M_{Ed} \leq M_{Rd}$ criterion for the first group of limit states in steel-concrete floors

Structural parameter	Normative condition (document)	Normative interpretation of influence on M_{Rd}	Conclusion for compliance with $M_{Ed} \leq M_{Rd}$
Concrete slab thickness	Normative requirements for the behaviour of concrete and reinforced concrete	Increasing thickness enhances the potential for the formation of the compressed zone and the integral resistance of the composite cross-section	With rational parameter ratios, the risk of M_{Ed} approaching M_{Rd} is reduced
Profiled decking geometry	Requirements for steel elements and profiles	Determines the structural capacity and effectiveness of engaging the steel component in bending	With geometrically compatible design, the range of permissible solutions is expanded; with incompatible geometry, it is limited
Degree of shear interaction	Conditions for considering full/partial interaction	Reduced interaction lowers the effective resistance of the composite cross-section and increases sensitivity to parameter variations	Partial interaction increases the likelihood of the criterion reaching its limit
Composite action scheme	Principles of composite action	Establishes the normative framework for the integral cross-section resistance as a result of the composite action of steel and concrete	When composite principles are observed, the criterion is formulated within the integral resistance model
Level of design load	Standardisation and load combinations	Increasing M_{Ed} raises the requirements for the integral cross-section resistance	Compliance with the criterion depends on the margin of M_{Rd} relative to M_{Ed}

Note: M_{Ed} – design bending moment from normative load combinations; M_{Rd} – design resistance (load-bearing capacity) of the composite cross-section in bending; criterion $M_{Ed} \leq M_{Rd}$ – fulfilment of the load-bearing capacity requirement according to the first group of limit states (ULS)

Source: SCN No. V.1.2-2:2006 (2006), SCN No. V.2.698:2009 (2009), SCN No. V.2.6-160:2010 (2010), DSTU No. B V.2.6-215:2016 (2016), SCN No. V.2.6-198:2014 (2022)

As followed from Table 1, the systematisation in the form “parameter – normative condition – effect” indicated that the fulfilment of the criterion $M_{Ed} \leq M_{Rd}$ for the first group of limit states was determined not by the individual effect of one or another parameter, but by the normatively determined interconnection of the geometric parameters of the cross-section and the conditions for implementation of the composite action in accordance with SCN No. V.1.2-6:2021 (2022). In this aspect, the thickness of the concrete slab was related to the possibility of the formation of the compressed area

and the level of involvement of the concrete component in the total resistance of the composite cross-section. An increase in the slab thickness at structurally justified ratios of the parameters was normatively perceived as an increase in M_{Rd} . The geometry of the profiled decking influenced the structural capacity and the level of involvement of the steel component in the resistance to bending moments in the composite system: at a geometrically coordinated arrangement, it was normatively perceived as an increase in the calculated resistance of the cross-section, and at a geometrically



uncoordinated arrangement, it was perceived as a restriction of the composite efficiency and a reduction of the permissible design range. The degree of shear interaction was a system-forming factor that determined the mode of operation of the cross-section (full or partial) and, accordingly, adjusts the normative ideas about the compatibility of deformations and the distribution of internal forces. A decrease in the level of shear interaction was normatively perceived as a reduction in the effective resistance of the composite cross-section and an increase in the sensitivity of the verification of the first group of limit states, in accordance with DSTU No. B V.2.6-215:2016 (2016). The composite action scheme was used to understand the resistance of the cross-section as an integrated property, while the design load value (determined in accordance with the standard combinations of actions) was the upper boundary of requirements for this integrated property. Therefore, the loadbearing capacity of the steel-concrete floor in the existing standard model was understood as a result of the design action coordination, geometric model of the composite cross-section and conditions for the implementation of the composite action as a result of shear interaction between the steel and concrete.

Influence of the degree of shear interaction on composite action of the floor

The degree of shear interaction between the profiled steel decking and the concrete slab determined the type of composite action of the steel-concrete floor and influences the implementation of transformed geometric and stiffness characteristics of the cross-section. In the existing standard model, this factor was used as an engineering indicator of the strain compatibility of the steel and concrete in the composite cross-section. The general provisions for the composite action and the requirement for ensuring strain compatibility of deformations were given in the SCN No. V.2.6-160:2010 (2010). When there was full shear interaction, the steel-concrete cross-section was calculated as a single composite section, with full implementation of the transformed geometric and stiffness parameters. In this condition, the internal forces between the steel and concrete were shared within the coordinated calculation scheme without reduction of the transformed parameters. The calculation parameters of the composite cross-section and the rules for accounting for the shear interaction were determined in accordance with the DSTU No. B V.2.6-215:2016 (2016), which formalised the contribution of steel and concrete to the resistance to bending moments and shear forces within the standard model. In the case of partial shear interaction, the design values of the effective geometric characteristics of the composite cross-section were decreased, which was normatively accounted for through adjustment of the transformed geometric parameters and design resistance. In this case, in the calculation formulas, the incomplete deformation compatibility

between the steel and concrete was taken into account, which imposed restrictions on the maximum allowable internal forces in the cross-section, when verified for the first group of limit states, in accordance with the SCN No. V.1.2-6:2021 (2022). Reduction of the degree of shear interaction was also accompanied by a decrease in the effective flexural stiffness of the steel-concrete element, which was manifested in an increase in the calculated values of deflections and an increase in the sensitivity of the verification results for the second group of limit states, in accordance with SCN No. V.1.2-6:2021 (2022). Therefore, the degree of shear interaction was an integral parameter that simultaneously affected the evaluation of both the load-bearing capacity and the serviceability of the steel-concrete floor in a unified normative calculation model. To clarify, the diagram of the composite action of the floor and the role of shear interaction between the steel decking and the concrete slab were presented in Figure 1. Analysis of the diagram showed that the transition from full to partial shear interaction between the profiled steel decking and the concrete slab was accompanied not only by a decrease in the realised level of the effective geometric and stiffness characteristics of the composite cross-section, but also by a qualitative change in the mechanism of its operation. In the case of full shear interaction, a steel-concrete cross-section works as a single beam with full compatibility of deformations, at the same time it realised the maximum possible transformed moment of inertia and the design moment resistance of the cross-section. Internal forces were redistributed between the steel and concrete parts of the section in accordance with their transformed stiffness characteristics, and the stress state of materials developed within the normatively acceptable limits without local overstrain. In the case of partial shear interaction between the components of the floor, there were longitudinal displacements, which disturbed the full compatibility of deformations and led to the redistribution of the bending moments. Within the framework of the normative model, the effective moment of inertia of the composite cross-section decreased, the transformed stiffness of the section was reduced, and the proportion of forces perceived by the concrete part of the section increases in comparison with the full interaction. According to the norm, this entailed a reduction in the realised moment resistance of the cross-section and an increase in its sensitivity to changes in the design parameters, primarily to the geometric parameters of the profiled decking and the characteristics of the shear connectors. In this connection, the degree of shear interaction was a determining factor that simultaneously influenced both the realisation of the load-bearing capacity of a steel-concrete floor and its deformability, which created conditions that may limit the fulfilment of the first and second groups of limit states within the current normative calculation model.



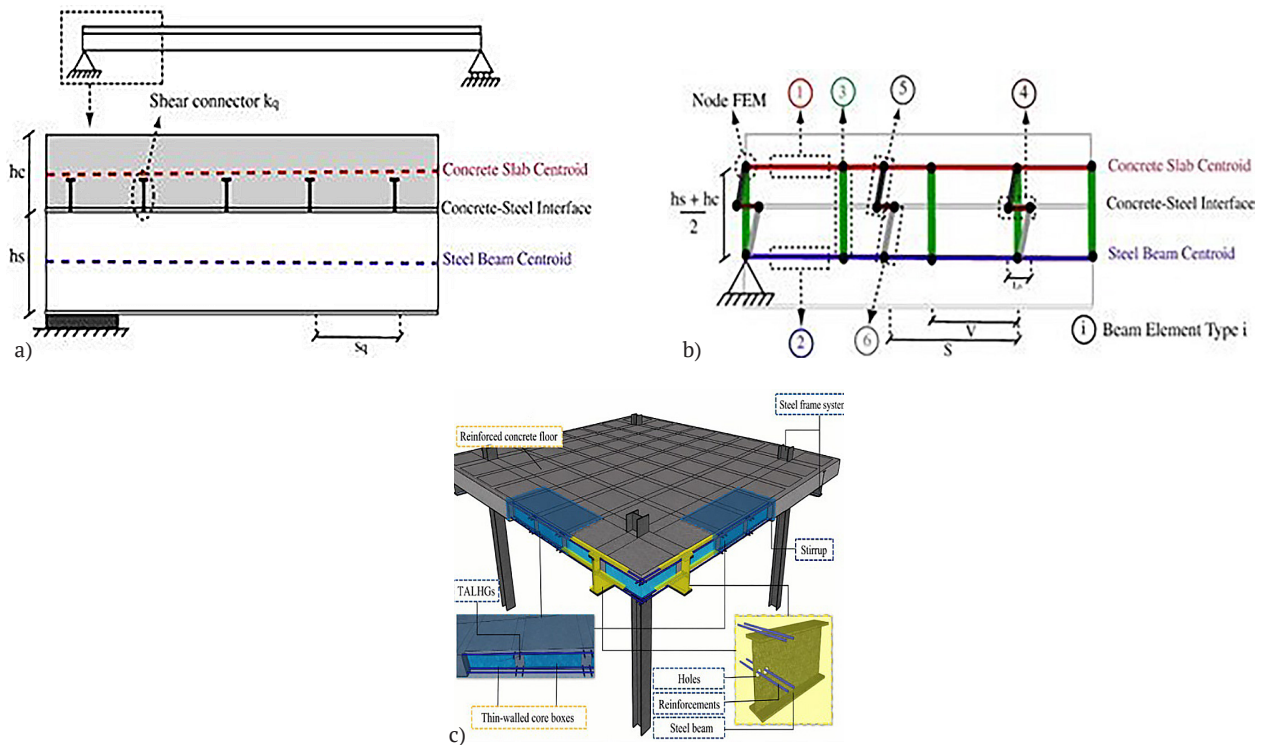


Figure 1. Schematic representation of the composite action of a steel-concrete floor, considering shear interaction between the profiled steel decking and the concrete slab

Note: a – design scheme of the steel-concrete floor showing the geometric configuration of the cross-section and the positions of the centroids of the steel and concrete components; b – generalised normative model of the composite element illustrating the mechanism of shear transfer between the profiled steel decking and the concrete slab; c – structural representation of the steel-concrete floor within the building’s load-bearing system. Symbols: h_s – height of the steel component of the composite cross-section; h_c – thickness of the concrete slab; S – design spacing of shear connectors; V – design transverse force; k_q – shear connection stiffness; FEM – finite element numerical model; TALHGs – thin-walled steel elements/profiles participating in the composite action of the floor

Source: SCN No. V.2.6-160:2010 (2010), DSTU No. B V.2.6-215:2016 (2016)

Deformability of steel-concrete floors under the second group of limit states

The calculation under the second group of limit states was a mandatory part of a comprehensive normative estimation of the floor’s performance and was carried out together with the calculation of the load-bearing capacity within a single calculation model. In the existing calculation model, the requirements for deformability were not secondary or derived; they were formalised as an independent calculation criterion, the provision of which was necessary for ensuring the serviceability of steel-concrete structures throughout their entire design life. In accordance with the requirements of the SCN No. V.1.2-6:2021 (2022), the deformability of the floors was classified as a serviceability criterion. For which the normative verification in the framework of the limit state method was obligatory. In the framework of the normative model, the design values of the steel-concrete floor deformability are determined by the effective stiffness of the composite cross-section. This, in turn, depended on the degree of participation of the profiled steel decking and the concrete slab in the composite action. The effective stiffness was determined using the

transformed geometric characteristics of the cross-section and the conditions of shear interaction between its components. At full shear interaction, the effective stiffness of the cross-section was determined based on the full participation of both the steel and concrete components in resisting the bending deformations. As a result, the steel-concrete floor works as a single bending element with a high efficiency of stiffness, and the design deflections do not exceed the normative limits. In the context of the normative assessment, the results of the first and second groups of limit states were interpreted based on the comparison of the design bending moment and floor deflections. This provided a comprehensive analysis of the effect of the degree of shear interaction on both the load-bearing capacity and deformability of the composite cross-section. At the same service loads, a decrease in the effectiveness of the composite action results in an increase in the design deflections of the floor compared to the case of full material compatibility. At partial shear interaction, the increase in the deflections occurred systematically and was caused by the reduced contribution of the steel component to the resistance of bending deformations within the composite



cross-section. In this case, the design deflections can attain the maximum permissible values according to the SCN No. V.1.2-6:2021 (2022). This was irrespective of the satisfaction of the requirements of the first group of limit states for the load-bearing capacity, which necessitates a

separate normative verification of deformability. To standardise the effect of the degree of shear interaction on the deformability of steel-concrete floors and the satisfaction of the second group of limit states, the characteristic regulatory dependencies were systematised in Table 2.

Table 2. Effect of the degree of shear interaction on the deformability of steel-concrete floors according to regulatory documents

Performance characteristic	Full shear interaction	Partial shear interaction	Normative reference
Compatibility of deformations	Complete along the entire span	Disrupted, with relative slips present	SCN No. V.2.6-160:2010 (2010)
Effective cross-section stiffness	Fully realised	Reduced	DSTU No. B V.2.6-215:2016 (2016)
Transformed moment of inertia	Close to full composite	Reduced	Normative consideration of partial interaction
Deflection level	Minimal	Increased	SCN No. V.1.2-6:2021 (2022)
Fulfilment of SLS requirements	Ensured with a margin	May reach limit	Restriction of design solutions

Note: SLS – compliance with normative requirements for serviceability criteria, including deflection/deformation limits ($w_{max} \leq w_{lim}$)

Source: developed by the author

From the analysis of the data in Table 2, it followed that in the regulatory calculations, the deformational behaviour of a steel-concrete floor was directly dependent on the degree of realised shear interaction between the profiled steel decking and the concrete slab. With full shear interaction, the strains of the deformations of the cross-section were compatible along the entire span, which made it possible to model the steel-concrete floor in the form of a single composite bending element with a maximally realised effective stiffness and a transformed moment of inertia, which was close to the moment of inertia of a fully composite cross-section. With partial shear interaction, the compatibility of deformations of the strains of the steel and concrete was violated, and relative displacements in the contact zone occur. In regulatory calculations, this was taken into account by reducing the effective stiffness of the composite cross-section and decreasing the transformed moment of inertia in accordance with the DSTU No. B V.2.6-215:2016 (2016). This led to an increase in the calculated deflections and increases the sensitivity of the results of checks for the second group of limit states to the adopted assumptions about the degree of composite action. With only partial realisation of the shear interaction, the fulfilment of the serviceability requirements can be close to a limiting one, which normatively narrowed the scope of possible design solutions. The obtained results confirmed the existence of a regulatory relationship between deformability and load-bearing capacity of steel-concrete floors. A decrease in the effective stiffness of a composite cross-section in the case of partial shear interaction simultaneously affected the verification according to both the first and second groups of limit states, which was reflected in different calculated parameters, such as a decrease in the design resistance of the cross-section and an increase in the deflections. In this case, the fulfilment of the load-bearing capacity requirements without ensuring a normatively acceptable level of deformability does not give a complete idea of the behaviour of a steel-concrete floor.

Integrated analysis of the relationship between load-bearing capacity and deformability of steel-concrete floors

A combined analysis of the regulatory and analytical evaluation of a steel-concrete floor according to both the first and second groups of the limit states showed that, within the framework of the current Ukrainian normative calculation procedure, the load-bearing capacity and deformability were related characteristics of a composite cross-section, SCN No. V.1.2-6:2021 (2022). In this approach, these parameters were not considered separately, but rather defined as a part of the stiffness-force combined mechanism of the steel-concrete floor, as the requirements of first and second limit state groups were interdependent parts of the normative assessment of the structure. The degree of shear interaction between the profiled steel decking and the concrete slab was common for determining the design resistance and transformed stiffness properties of the composite cross-section. A change of this parameter was always accompanied by a corresponding change of the design bending resistance and effective stiffness of the steel-concrete element, which in turn had a direct influence on the design deflections and the nature of the deformational behaviour of the floor in service conditions. When there was full shear interaction, the steel-concrete cross-section was calculated as a single bending element, with full implementation of the transformed geometric and stiffness parameters. In this case, the internal forces were distributed between the steel and concrete components in proportion to their transformed stiffnesses; the deformations of the components remained compatible along the span; and the design deflections remained within the limits established for the second group of limit states. A partial realisation of the shear interaction reduced the efficiency of the composite action of the cross-section, which was taken into account normatively by changing its transformed stiffness characteristics. From a structural point of view, this reduction

manifested itself as a decrease in the realised design resistance of the cross-section. From a stiffness point of view, this reduction led to an increase in the design deflections under the same service loads. These changes had a direct effect on the results of the second group of the limit state checks. An asymmetric sensitivity of the first and second groups of limit state criteria to a reduction of the degree of shear interaction was observed: in the case of partial composite action, the fulfilment of the load-bearing capacity requirements can still be ensured, while the design deflections more rapidly approach their maximum allowable values adopted by normative standards. In these cases, it was the results of the serviceability checks that dictated the admissibility of design and construction solutions in the regulatory framework. The integrated view of the normative dependence between the load-bearing capacity and deformability was given in Figure 2.

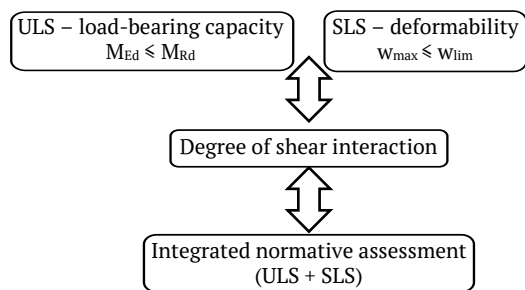


Figure 2. Integrated scheme of the normative interaction between load-bearing capacity and deformability indicators of a steel-concrete floor
Source: SCN No. V.2.6-160:2010 (2010), DSTU No. B V.2.6-215:2016 (2016), SCN No. V.1.2-6:2021 (2022)

From the scheme, it was seen that the degree of shear interaction between the profiled steel decking and the concrete slab acts as an integrating parameter that simultaneously controlled the strength and stiffness parameters of the composite cross-section of the steel-concrete floor. It directly affected the design deflections of the floor from the service loads due to changes in the effective stiffness of the cross-section, and through changes in the transformed geometric characteristics, it affected the achieved design bending resistance and load-bearing capacity of the element. A decrease in the effectiveness of the composite action causes coordinated changes in the indicators of both the first and second groups of limit states, without their individual manifestation, which reflected the integration of the normative constraints on the floor in a single design model. With partial composite action, the fulfilment of the load-bearing capacity requirements can be preserved due to the availability of some constructive reserve of the cross-section, while the design deflections more quickly approached their maximum allowable standard values, even at a slight decrease in the effective stiffness. In this case, the second group of limit state requirements determined the acceptability of design solutions in the

normative model and actually limits the further application of individual structural solutions. Summarising, it can be argued that the load-bearing capacity and deformability of steel-concrete floors developed as interrelated characteristics of the composite cross-section in a unified normative evaluation system. In this system, the degree of shear interaction provided for the simultaneous fulfilment of the first and second groups of limit state requirements, ensured the consistency of the strength and deformation parameters, and limited the field of admissible design solutions in terms of the safety and serviceability of the floors.

DISCUSSION

The regulatory and analytical assessment of the load-bearing capacity and deformability of steel-concrete floors with profiled decking presented in this research demonstrated the key importance of the degree of shear interaction for the adopted normative model of the behaviour of composite cross-sections. It has been shown that the efficiency of the transfer of longitudinal shear forces between the steel decking and the concrete slab was directly related to the strength and stiffness characteristics of the floor, since the contact interaction defined the deformation compatibility of the components and, therefore, the redistribution of the internal forces in the composite cross-section. In this sense, the composite cross-section was understood as an integral system, in which the contact interaction of the components determined the realised transformed section characteristics, the position of the neutral axis and the proportion of the contribution of each component to the resistance to bending. This understanding was in agreement with the survey conclusions presented in K. Mohammed *et al.* (2017), in which steel-concrete floors were understood as a structural system, which was primarily sensitive to the actual composite action, rather than to the physico-mechanical characteristics of the individual component materials taken separately. This agreement followed from a common understanding of composite action as a stiffness-force mechanism, within which local contact effects cumulatively determined the integral performance characteristics of the floor. From the point of view of the serviceability of structures, this conclusion can be further refined as a result of long-term effects occurring in the concrete component, in particular, the specific influence of drying and shrinkage of composite slabs with profiled decking.

The mechanism of reduced efficiency of composite action and its influence on the realised resistance of the composite element was in agreement with the conclusions presented in study by N.A. Hedaoo *et al.* (2012), in which it was demonstrated by experimental and analytical comparison that a decrease in the efficiency of bonding or interaction between the components of the composite cross-section led to incomplete utilisation of the steel component, when resisting bending forces. From the design point of view, the latter effect results in a change in the effective degree of compositeness represented by the value of the design bending resistance M_{Rd} and the shift in the



neutral axis of the section in the current model. The convergence of the two approaches can be explained by the same root cause: a reduction in the degree of shear connection changes the deformation compatibility of the component layers, the position of the neutral axis and the internal force distribution between the concrete and steel elements and, as a result, changes the effective strength and stiffness properties of the system. Concerning serviceability, it was crucial to keep in mind that the deformation capacity of a composite floor was not only affected by the current properties of the component materials but also dependent on time and environmental conditions. This was in line with the results by Y. Wei *et al.* (2020), who showed that the relative humidity affects the creep of concrete and, thus, the time-dependent accumulation of deformation. In the framework of SLS, this meant that for the same geometrical and loading conditions, a change in the environmental conditions results in a change in the evolution of deflection and, consequently, in the effective stiffness during the service life for the same loading conditions.

The sensitivity of deformation parameters and transformed cross-section properties to the degree of partial composite action was also in agreement with the experimental results by A. Siva *et al.* (2016), who pointed out that, when the slab was partially composite, a change in the deformation behaviour of the slab was observed before the ultimate limit state was reached, i.e., before the deformative signs of insufficient compositeness in terms of strength. In the design framework adopted herein, the latter was reflected by the fact that a reduction in the degree of shear interaction results in a reduction of the effective stiffness of the composite cross-section and, hence, in an increased rate of deflection in comparison to the change in the remaining strength capacity. The inclusion of long-term deformability in SLS verification was in line with the findings by Y. Wang *et al.* (2016) about the cumulative long-term deflection of the composite slab due to creep and shrinkage of concrete. In the context of the present regulatory and analytical formulation, this was related to the dominant role played by SLS verifications in the case of partial compositeness, even when the verifications of the first group of limit states were already fulfilled, as a result of the long-term processes in the concrete component, which reduced effective stiffness over time and increase deflections. The consideration of shear interaction was related to the geometrical features of the contact surface, namely, the profile shape of the profiled decking. Such dependence has been addressed by J.H.L.M. Mello *et al.* (2024), who concluded that the embossment geometry influences the longitudinal shear force transmission and, therefore, the verification of the longitudinal shear capacity. In the present context, this dependence meant that the geometrical features of the decking influence the achieved level of composite action and, therefore, the resulting transformed cross-section features.

The dependence on geometrical proportions and the load level was also extended to the combined response of

strength and deformability. An experimental analysis carried out by S. Sirimontree *et al.* (2021) concluded that variations of the shear span-to-depth ratio influence not only the ultimate values but also the deformation capacity of composite slabs. In normative terms, this translated into a reduction of the effective flexural stiffness that was mostly accounted for by an increase in the deflection (reduction of the partial composite action degree), whereas the variation of the load-bearing capacity may be less significant for the same conditions, thus leading to a nonsimultaneous variation of the sensitivity of the ULS and SLS verifications. Analogous conclusions concerning the role of the contact surface have been reported by J. Song *et al.* (2021) based on an experimental campaign that concluded that an increase in deflection was obtained, when the stiffness of the contact surface between the steel sheets and the concrete was decreased. The contribution of contact deformation to the total deformative response of the floor was therefore concluded. Simultaneously, the parameters of the concrete component were significant with respect to the deformability of composite slabs: variations in the effective modulus of elasticity and long-term deformation parameters affected deflection magnitudes and determined the stiffness response of the system under service loads. In the case of partial composite action, the sensitivity of deflections to concrete parameters was higher due to a reduced reserve of structural stiffness.

The review provided by M.M. Rahman & G. Ranzi (2022), which systematised the behaviour of steel-concrete slabs with respect to shrinkage deformations, showed that non-uniform drying or shrinkage in the presence of steel decking changes the deformation pattern over time. In the context of the present interpretation, this confirmed the conclusion that SLS criteria were of particular relevance in the conditions of partial composite action, where the reduction in effective stiffness made the floor more sensitive to long-term deformations of the concrete component. The analytical models of long-term behaviour, used in the regulatory and analytical approach, showed that the deformability of the floor can be the factor determining the acceptability of a design solution, even when the requirements of the first group of limit states were satisfied. Similar conclusions were reported by Q. Wang *et al.* (2022), where the increase in deflections was attributed to concrete creep and the gradual loss of effective stiffness in composite slabs over time. From the methodological point of view, this raised the question of the correspondence between code-based procedures and the real in-service performance of the structure, as well as the interpretation of the results of an assessment.

In the study of L.A.M. Oliveira *et al.* (2021) devoted to the analysis of design codes in relation to the in-service performance of steel-concrete composite slabs, an approach was justified, in which SLS and ULS verifications should be considered as independent with respect to the criteria and consequences, without a direct transfer of conclusions between groups of limit states. Within the framework of the





present study, this meant that, under conditions of partial composite action, deflections may increase in a disproportionate way with respect to variations in the strength reserve, and therefore, serviceability can impose constraints on a design solution independently of the results of the ULS assessment. The difference in approaches was possible regarding the evaluation of reliability and reserves: D. Gino *et al.* (2019), when applying the partial factor approach of fib Bulletin 80 to an existing object, showed the need for the explicit consideration of uncertainties and the formal reservation within the verification procedure. In the framework of the considered problem, this was manifested in the difference in sensitivity of deflections and the design bending resistance to a change in the degree of shear interaction, due to the different physical essence of stiffness and strength characteristics of the composite cross-section.

The data on the long-term behaviour of the floor were in line with the conclusions of the studies of H. Zhang *et al.* (2022), which mentioned the accumulation of deformations in composite slabs under long-term loading. In the regulatory and analytical perception, this can be explained by an increase in deflections with time at a constant service load due to a gradual decrease in the effective stiffness of the composite cross-section. At partial composite action, the effect of long-term behaviour is connected with a smaller reserve of stiffness and greater sensitivity of the total deformation reaction to the contact interaction. The decrease in stiffness of separate elements of the composite should be perceived as influencing the stress-strain state of the system as a whole, rather than as a local phenomenon. In the research of D. Baranetska *et al.* (2025), the results of calculations were presented, which characterised the systemic change in the reaction of the structure, when changing the stiffness parameters of its components. In the normative perception, this can be treated as evidence of the composite action as a unified stiffness-force mechanism, where the degree of shear interaction affected both the realised resistance and the deformability of the system. In the framework of the carried-out analysis, the revealed regularities can be commented as a complexity of the composite action in steel-concrete floors and an interdependence of force and stiffness parameters within a unified mechanism.

In the article of V. Popov *et al.* (2011), the load-bearing capacity and deformability of steel-concrete floors were considered as interconnected characteristics, which were formed as a result of the composite action of the steel and concrete components. These provisions of the normative document can be used to explain the systematic behaviour of composite floors and the relationship between the force and stiffness reactions. In the study of V. Sirobaba (2018), it was revealed that in the conditions of partial composite action, it was the deformability characteristics that determined the boundaries of the admissible design solutions of steel-concrete floors. The same picture was observed in this research, where the limiting state was the achievement of maximum deflections at earlier stages of loading than the realisation of ultimate stresses. This was due to the

high sensitivity of the effective stiffness of the composite cross-section to a decrease in the degree of shear interaction between the profiled steel deck and the concrete slab. The general regulatory and analytical conclusion about the determining role of the effective stiffness and the parameters of composite action, which simultaneously controlled the load-bearing capacity and the deformational behaviour of the floors, fully agreed with the experimental and computational data, in which these same processes were directly registered by the load-deflection curve and the realised bending behaviour of the composite slabs. Bending behaviour of composite slabs with profiled steel decking was also studied by G. Zhu *et al.* (2025), where by experiment and computational simulation it was found that the parameters of the structure affected the load-deflection curve and the failure mode, and the analytical calculation based on the effective stiffness was suitable for use in design calculations to determine the deflection and load-bearing capacity of slabs. In the study of K.T. Huong *et al.* (2025), it was experimentally confirmed that the parameters of composite action between the profiled steel deck and the concrete slab determined the achieved load-bearing capacity and the deformation behaviour of the elements due to a change in the effective stiffness of the composite cross-section. Similar reductions of shear interaction efficiency were identified in the present study as a factor responsible for the premature growth of deflection, and consequently for the prevailing effect of SLS in cases, where the requirement $M_{ed} \leq M_{Rd}$ was still satisfied.

The combined results of the regulatory and analytical assessment showed that the degree of shear interaction between the profiled steel decking and the concrete slab determined a unique stiffness-force response of the steel-concrete floor, where designed bending resistance and service deformability were both simultaneously defined. These relationships appeared to be consistent with the evidence of experimental and numerical investigations on partial composite action, where the efficiency of longitudinal shear forces determined the stress distribution, the position of the neutral axis and the magnitude of the equivalent stiffness parameters of the cross-section. For partial composite action, deflections were observed to increase at a faster rate than reductions in load-bearing capacity, in line with analytical and engineering-normative perceptions of the uneven sensitivity of the first and second limit state verifications. The overall set of comparisons offered a consistent normative description of the response of steel-concrete floors, where serviceability and load-bearing capacity were not perceived as separate entities but rather as correlated outcomes of composite action, in line with contemporary trends in research and engineering practice on steel-concrete systems.

CONCLUSIONS

The regulatory and analytical assessment offered a unified description of the development of loadbearing capacity and deformability of steel-concrete floors reinforced with profiled steel decking in the context of the current design



framework for the first and second groups of limit states, with a distinction between the ULS and the SLS requirements. In the normative model adopted for the study, these characteristics were not separate entities but rather were both ruled by a unified stiffness-force mechanism of the composite cross-section, where the outcomes of load-bearing capacity and serviceability verifications were correlated counterparts of the safety and performance evaluation of the structure. A degree of shear interaction between the profiled steel decking and the concrete slab guarantees an involvement of the floor's strength and stiffness properties in a combined design model, and influenced the realised design bending resistance and the effective stiffness element. The complete shear interaction realised a monolithic behaviour of a steel-concrete cross-section in a standard design model, the highest possible involvement of geometrical, stiffness properties of the transformed section, and the lowest possible deflection values. All of this guarantees the fulfilment of the requirements of the first and second groups of limit states in terms of standard admissible values of the design load combinations. The partial realisation of composite action was accompanied by the corresponding decrease of the design resistance and increase of deflection values, i.e., the effective stiffness of a cross-section

is reduced under the same loading conditions. It was also observed that, under partial shear interaction, deformability indicators (deflections) reach the SLS limit values more quickly than a reduction of the load-bearing capacity reserve takes place, was also found. The obtained result predetermined an asymmetric sensitivity of ULS and SLS criteria and thus the acceptability of design solutions. The use of normatively generalised design models without verification for specific types of structural solutions and contact zone configurations was a limitation of the study. In the future, a numerical and experimental refinement of the influence of local contact zone parameters, long-term action of concrete properties (shrinkage, creep) and an optimisation of standard procedures for an account of the partial composite action in steel-concrete floors are foreseen.

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**Василь Петрів**

Аспірант

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Несуча здатність та деформативність сталобетонних перекриттів по профільованому сталевому настилу

Анотація. Метою статті було нормативно-аналітичне обґрунтування впливу ступеня зсувної взаємодії на виконання вимог першої та другої груп граничних станів композитних перекриттів із профільованим настилом. Методологія дослідження ґрунтувалася на нормативно-аналітичному підході з використанням чинної національної нормативної бази України та нормативно визначених розрахункових моделей сталобетонних перекриттів як композитних згинальних елементів, для яких у межах нормативної розрахункової моделі приймалася повна або часткова сумісність деформацій сталевих та бетонних складових. Результати дослідження показали, що несуча здатність і деформативність перекриттів формувалися як взаємопов'язані характеристики в межах єдиного жорсткісно-силового механізму роботи композитного перерізу. Було встановлено, що ступінь зсувної взаємодії між сталевим настилом і бетонною плитою є інтегруючим параметром, який одночасно визначав реалізований розрахунковий опір згину та ефективну жорсткість перекриття. За умов повної зсувної взаємодії забезпечувалася максимальна реалізація приведених геометричних і жорсткісних характеристик перерізу та виконання вимог обох груп граничних станів. За часткової композитної роботи було зафіксовано узгоджене зниження розрахункового опору та зростання прогинів, причому деформативні показники виявляли вищу чутливість до зменшення ефективної жорсткості, ніж показники несучої здатності. Показано, що за однакових експлуатаційних навантажень прогини могли досягати гранично допустимих значень раніше, ніж реалізовувалися граничні напруження, що визначало експлуатаційну придатність як обмежувальний чинник проєктних рішень. Практична значимість отриманих результатів полягала в можливості їх використання проєктними та експертними організаціями у практиці нормативного оцінювання і проєктування сталобетонних перекриттів із профільованим настилом

Ключові слова: композитна робота; зсувна взаємодія; експлуатаційна придатність; ефективна жорсткість; прогини; граничні стани

