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PERFORMANCE EVALUATION OF STEEL-CONCRETE COMPOSITE DECK SLAB SYSTEMS FOR LONG-SPAN BUILDINGS AND COMPOSITE BRIDGES

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ABSTRACT

Composite construction, in which structural steel and reinforced concrete act as one unit through mechanical shear connection, is a preferred solution for long span buildings and highway bridges. This paper presents a data-driven analytical study of steel–concrete composite members, focusing on the behaviour of the composite deck slab in buildings and bridges. A parametric dataset was generated using limit state procedures aligned with Eurocode 4 and IS 11384 for building beams of 12–36 m span, bridge girders of 20–60 m span, profiled-sheet composite slabs, bridge deck slabs under wheel loading, and beams with partial shear connection. The results are reported in five tables and five figures and are examined through descriptive statistics and linear regression. Composite action reduced structural steel weight by 22–32% in building beams and 34–56% in bridge girders, and the saving declined linearly with span (R^2 = 0.92 and 0.90). Building deck slabs on 1.0 mm profiled sheeting were governed by shear bond, with utilisation between 0.43 and 1.00. Bridge deck slabs carried equivalent loads of 27–54 kN/m², two to four times those in buildings, and design moment grew almost linearly with girder spacing (R^2 = 0.995). Sixty percent shear connection cut studs by 40% while lowering moment capacity by 20% and raising deflection by 3.5%.

Keywords: *Composite construction[1], Steel–concrete composite[2], Composite deck slab[3], Long span buildings[4], Composite bridges[5], Shear connection[6], Data analysis[7].*

1. INTRODUCTION

1.1 Background and Significance

Composite construction combines the tensile strength and ductility of structural steel with the compressive strength, stiffness and fire resistance of concrete. When the two materials are connected by shear studs or similar devices, the slab acts as the compression flange of the steel section, which raises flexural capacity and stiffness at little additional cost [1], [8]. Long span buildings such as offices, airports, exhibition halls and hospitals need column-free floors, and composite beams carrying profiled-deck slabs deliver these spans with shallow depth and rapid construction [9], [10]. Highway and railway bridges use the same principle, with a reinforced concrete deck acting compositely with plate or box girders [3], [30]. Indian practice for such systems is set out in IS 11384 and IRC:22, while Eurocode 4 offers a widely used parallel framework [2], [4], [6].

1.2 Problem Statement and Motivation

Although the principles are well established, the behaviour of the composite deck slab differs sharply between the two applications. In buildings the slab is thin, cast on permanent profiled sheeting and governed largely by shear bond between sheet and concrete [15], [17]. In bridges the slab is a thick reinforced section that resists concentrated wheel loads, participates in global girder action and is exposed to fatigue and cracking. Designers often treat these cases separately, and comparative numerical evidence that links slab behaviour, girder efficiency, connection demand and serviceability is scarce. Vibration and partial shear connection further complicate long span design, because they can override strength as the governing criterion [22]. A consolidated data analysis is therefore needed to support rational choices between the two systems and to guide preliminary design decisions.

1.3 Objectives and Scope

This paper pursues four objectives: to quantify the steel saving obtained from composite action in long span building beams and bridge girders; to compare the response of profiled-sheet composite slabs in buildings with reinforced concrete deck slabs in bridges; to establish how the degree of shear connection affects strength, stud demand and deflection; and to identify the serviceability limits that govern long spans. The scope covers simply supported members, building spans of 12–36 m and bridge spans of 20–60 m, and limit state design under static loading. Fatigue, creep, shrinkage, continuous spans and fire are outside the scope, and the results are intended as a comparative, design-oriented dataset for design offices and researchers rather than as a substitute for project-specific analysis. The analysis is deliberately transparent, so every value can be reproduced by hand calculation.

2. LITERATURE SURVEY

Research on steel–concrete composite behaviour began with tests on composite beams and the recognition that interface slip reduces stiffness and strength [14]. Effective width, shear lag and construction stage effects were subsequently codified in national standards such as IS 11384, IS 800, EN 1994 and AISC 360 [2]–[7]. Newmark et al. formulated the classic partial interaction theory for beams with flexible connectors [11], and later authors

extended it to include shear deformation, creep and nonlinear connector response [26]–[28]. The effect of slip on deflection is recognised as significant for long spans with few connectors [26], [27]. Studies of headed studs by Viest and by Ollgaard et al. produced the empirical strength relationships that underpin present design equations [12], [13], while subsequent work examined connector stiffness, large-diameter studs and finite element models of stud behaviour [23]–[25]. For beams in buildings, Johnson and Molenstra examined the consequences of partial shear connection and provided the basis for the linear interaction rules used in current codes [2], [22]. Research on slabs concentrated on profiled steel sheeting. Porter and Ekberg proposed design recommendations for steel deck floor slabs, and Wright et al. described the practical use of profiled sheeting in floors [15], [16]. Daniels and Crisinel analysed composite slab strength and shear-bond failure, and Veljkovic studied the behaviour and resistance of composite slabs [17], [18]. The m–k method, derived from full-scale tests, was applied to embossed sheets by Marimuthu et al., whereas Abdullah and Easterling proposed a small-scale test alternative and Chen and Shi developed finite element models of the shear bond mechanism [19]–[21]. For bridges, Brozzetti reviewed the development of composite bridge design, and finite element studies of composite plate girders were reported by Baskar et al. [29], [30]. Slabs in bridges have received attention mainly as reinforced concrete decks acting with girders, where local wheel load bending, cracking and fatigue are the principal concerns [3], [6]. Guidance on serviceability, including deflection limits and floor vibration, appears in design guides and standards rather than in isolated experimental papers [1], [5], [10]. Design manuals by Johnson, Nethercot, and Oehlers and Bradford consolidate this knowledge [1], [8], [9]. Despite this large body of work, most studies treat buildings and bridges separately and rely on individual tests or models. Few papers offer a common parametric dataset, analysed statistically, that compares slab behaviour, girder efficiency and connection demand across both applications, and this gap motivates the present study.

3. METHODOLOGY

The study adopts a data-driven analytical design. Instead of laboratory testing, a parametric programme was executed in Python using closed-form limit state expressions from Eurocode 4 and IS 11384 [2], [4]. Five spans were considered for building beams (12, 18, 24, 30 and 36 m) and for bridge girders (20, 30, 40, 50 and 60 m). Each member was designed twice, once as bare steel and once with full composite action, so that the difference in steel weight isolates the benefit of composite behaviour. All outputs were tabulated and examined using descriptive statistics, Pearson correlation and least-squares regression. Materials and loading were fixed. Structural steel had a yield strength of 345 MPa with a partial factor of 1.10, and concrete was M30 for buildings and M40 for bridges. Building beams at a 6 m bay width carried 5.5 kN/m² dead and 4.0 kN/m² live load on a 130 mm slab cast over 60 mm profiled sheeting. Bridge girders at 3 m spacing carried a 225 mm deck, a wearing course and equivalent live loads of 18–26 kN/m. Sections were sized for plastic moment capacity, unpropped construction stage strength and live load deflection limits of span/360 for buildings and span/800 for bridges. Slab behaviour was analysed separately. Building deck slabs were checked by the m–k shear-bond method with m = 190 N/mm², k = 0.05 N/mm² and a partial factor of 1.25, together with service deflection based on the mean of cracked and uncracked stiffness [17], [19]. Bridge deck slabs were analysed for a 100 kN wheel load using an effective strip width and limit state flexural design.

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4. DATA COLLECTION AND ANALYSIS

4.1 Dataset and Presentation

The dataset comprises 5 building beam designs, 5 bridge girder designs, 9 building deck slab cases, 5 bridge deck slab cases and 4 shear connection levels, giving 28 design records. Each record was generated by the procedure described above, and every reported value is either a direct output or a ratio derived from outputs. Tables 1 to 5 present the data, and Figures 1 to 5 illustrate the trends. Regression statistics are quoted in the text where they strengthen the interpretation, and all percentage savings are measured relative to the bare steel design of identical span and loading.

4.2 Composite Deck Slab Systems

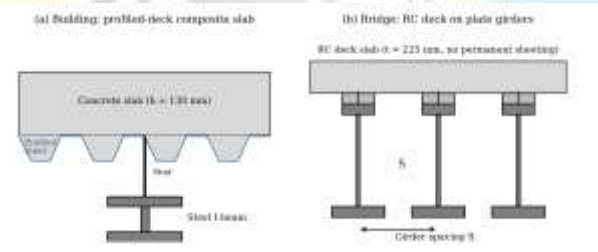


Figure 1: Schematic of composite deck slabs: (a) building slab on profiled sheeting; (b) bridge reinforced concrete deck on plate girders.

Figure 1 contrasts the two deck slab systems examined in this study. In the building system, a 130 mm slab is cast on trapezoidal profiled sheeting that serves first as formwork and later as tensile reinforcement, with headed studs welded through the sheet to the beam flange. In the bridge system, a 225 mm reinforced concrete slab spans transversely between girders spaced at S and is connected by studs on the top flange. Because wheel loads are concentrated and repeated, the bridge slab relies on top and bottom bars rather than sheeting, which changes both the failure mode and the design demand.

4.3 Building Beams: Steel Saving

Table 1: Steel Weight of Bare Steel and Composite Building Beams (6 M Bay, Dl 5.5 Kn/M², Ll 4.0 Kn/M²)

Span L (m)	Depth, bare (mm)	Depth, composite (mm)	Weight, bare (kg/m)	Weight, composite (kg/m)	Saving (%)	f_1, composite (Hz)
12	600	480	156.0	106.5	31.7	3.34
18	900	720	236.6	163.0	31.1	2.57
24	1200	960	316.7	223.4	29.5	2.17
30	1500	1200	398.6	295.2	25.9	1.89
36	1800	1440	482.3	374.6	22.3	1.70

Table 1 presents the design outcome for building beams. Composite action reduced steel weight from 156.0 to 106.5 kg/m at 12 m and from 482.3 to 374.6 kg/m at 36 m, savings of 31.7% and 22.3% respectively. Regression of saving on span gave saving = 37.7 − 0.399L with $R^2 = 0.924$, so the benefit diminishes as span increases because the slab width is capped at the 6 m beam spacing while loads keep growing. Composite depth was kept at span/25

against span/20 for bare steel, a 20% depth reduction that is valuable for floor-to-floor height. Steel weight rose almost linearly with span, at 11.1 kg/m per metre for composite beams and 13.6 kg/m per metre for bare steel ($R^2 > 0.99$).

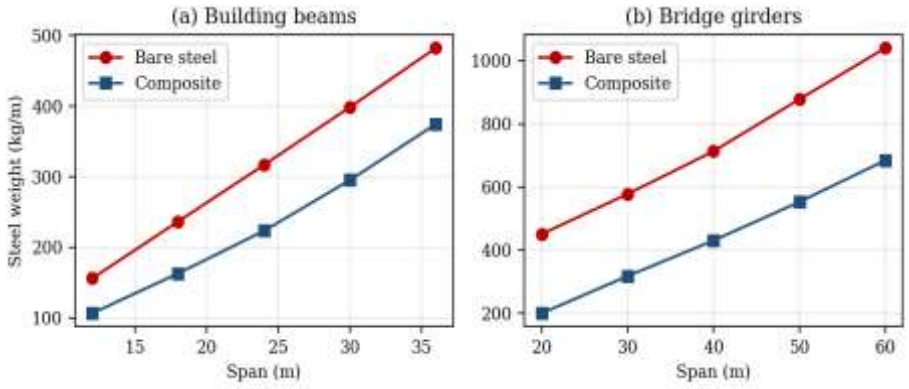


Figure 2: Steel weight versus span: (a) building beams (Table 1); (b) bridge girders (Table 4).

Figure 2 plots the steel weights of Table 1 and Table 4 against span. In both panels the composite curve lies below the bare steel curve, and the vertical gap represents the steel saved through composite action. In the building panel the two lines converge slowly whereas in the bridge panel the gap is much wider because the deflection limit of span/800 penalises the more flexible bare steel girder. Both composite curves are nearly straight, which suggests that a simple linear rate per metre of span can be used for preliminary estimates of steel tonnage in long span design [1], [9].

4.4 Building Deck Slab: Shear-Bond Behaviour

Table 2: Shear-Bond Capacity and Service Deflection of Building Composite Deck Slabs (1.0 Mm Sheeting)

Slab h (mm)	Span (m)	Capacity w_Rd (kN/m²)	Factored load (kN/m²)	Utilisation	Deflection (mm)	Span/ deflection
120	2.5	24.8	13.2	0.53	3.8	665
120	3.0	17.6	13.2	0.75	7.8	385
120	3.5	13.2	13.2	1.00	14.4	242
130	2.5	27.5	13.6	0.49	2.9	852
130	3.0	19.6	13.6	0.69	6.1	493
130	3.5	14.7	13.6	0.92	11.3	310
150	2.5	33.0	14.2	0.43	1.9	1319
150	3.0	23.5	14.2	0.61	3.9	763
150	3.5	17.6	14.2	0.81	7.3	481

Table 2 gives shear-bond capacity, applied load and service deflection for building deck slabs. For a 130 mm slab, capacity fell from 27.5 to 14.7 kN/m² as span increased from 2.5 to 3.5 m, so utilisation against the 13.6 kN/m² factored load rose from 0.49 to 0.92. The 120 mm slab reached a utilisation of 1.00 and a deflection of span/242 at 3.5 m, which exceeds the span/250 guide, whereas the 150 mm slab remained at 0.81. Capacity is therefore highly sensitive to shear span because the m-term is inversely proportional to it, and thicker slabs increase resistance by enlarging the effective depth.

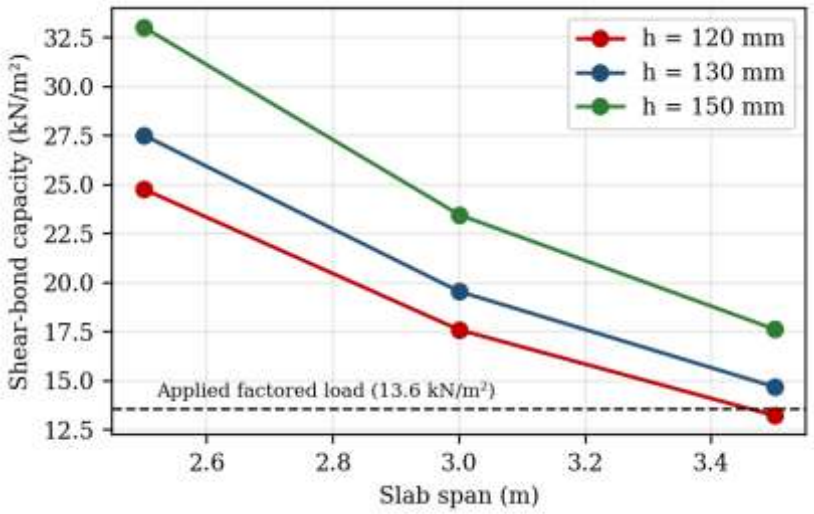


Figure 3: Shear-bond capacity of building deck slabs versus span.

Figure 3 presents shear-bond capacity against slab span for the three thicknesses, with the applied factored load drawn as a dashed line. All curves decrease with span, and the point where a curve meets the dashed line marks the maximum span at which the slab remains adequate. The 120 mm slab reaches the load level at 3.5 m, the 130 mm slab approaches it, and the 150 mm slab retains a margin. The figure therefore converts Table 2 into a design chart: for a chosen thickness the permissible span can be read directly, and extra thickness shifts the curve upward.

4.5 Bridge Deck Slab and Composite Girders

Table 3: Bridge Deck Slab Response Under A 100 Kn Wheel Load (M40 Concrete, Fe 500 Steel)

Spacing S (m)	Slab t (mm)	Strip width (m)	M_LL (kN·m/m)	M_DL (kN·m/m)	M_u (kN·m/m)	A_st (mm²/m)	Equiv. UDL (kN/m²)
2.5	200	2.04	24.6	4.2	42.5	680	54.4
3.0	225	2.31	26.0	6.5	47.8	651	42.5
3.5	250	2.58	27.1	9.7	53.7	636	35.1
4.0	275	2.86	28.0	13.6	60.4	633	30.2
4.5	300	3.13	28.7	18.5	68.1	641	26.9

Table 3 summarises bridge deck slabs designed for a 100 kN wheel load. As girder spacing increased from 2.5 to 4.5 m, the strip width grew from 2.04 to 3.14 m and the live load moment rose modestly from 24.6 to 28.7 kN·m/m, while the dead load moment increased from 4.2 to 18.5 kN·m/m because the slab was thickened from 200 to 300 mm. Design moment therefore increased almost linearly, by 12.8 kN·m/m per metre of spacing ($R^2 = 0.995$). Required reinforcement stayed near 630–680 mm²/m, but the equivalent uniform load fell from 54.4 to 26.9 kN/m², which is roughly two to four times the 13.2–14.2 kN/m² applied to building slabs.

Table 4: Composite Bridge Girder Performance (3 M Girder Spacing, 225 Mm Deck)

Span L (m)	Depth, composite (mm)	Weight, bare (kg/m)	Weight, composite (kg/m)	Saving (%)	LL deflection (mm)	Span/ deflection	f_1 (Hz)
20	800	451.1	200.1	55.6	25.0	800	3.10
30	1200	577.9	318.1	45.0	37.5	800	2.37
40	1600	713.4	430.6	39.6	50.0	800	1.95
50	2000	878.2	553.0	37.0	62.5	800	1.66
60	2400	1040.5	684.6	34.2	75.0	800	1.44

Table 4 reports composite bridge girder performance. Steel weight fell from 451.1 to 200.1 kg/m at 20 m (a 55.6% saving) and from 1040.5 to 684.6 kg/m at 60 m (34.2%). The saving is larger than in buildings because the 225 mm deck provides a large concrete flange and because the span/800 deflection limit governed every span, so the live load deflection of the composite girders equals 25.0 mm at 20 m and 75.0 mm at 60 m. Saving decreased with span as saving = $62.6 - 0.508L$ ($R^2 = 0.904$). Fundamental frequency dropped from 3.10 to 1.44 Hz, indicating rising sensitivity to traffic-induced vibration.

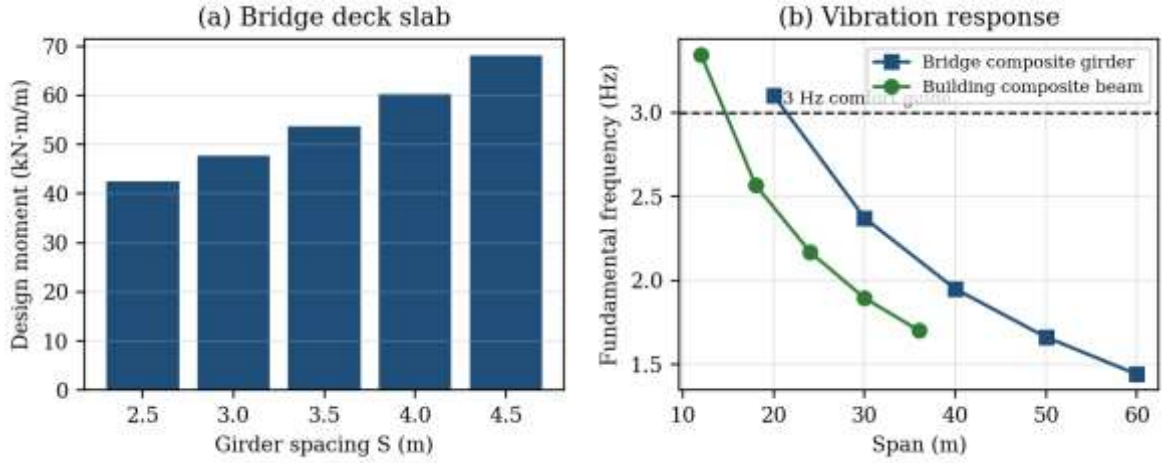


Figure 4: (a) Bridge deck slab design moment versus girder spacing; (b) fundamental frequency versus span.

Figure 4 combines two indicators drawn from Tables 1, 3 and 4. Panel (a) shows bridge deck slab design moment rising almost linearly with girder spacing, confirming the regression trend. Panel (b) shows fundamental frequency against span for composite building beams and bridge girders, together with a 3 Hz guide value. Both curves decline with span roughly in proportion to $1/L^2$ and pass below the guide shortly after 12 m for buildings and 20 m for bridges. Long span composite members can therefore satisfy strength requirements with ease yet still need added stiffness or mass control to achieve acceptable vibration behaviour [1], [10].

4.6 Degree of Shear Connection

Table 5: Effect of Degree of Shear Connection on A 24 M Composite Building Beam (19 Mm Studs)

Degree η	Studs per half span	Stud spacing (mm)	Moment capacity M_Rd (kN·m)	M_Rd / M_Ed	Deflection ratio δ/δ_full
0.4	41.1	292	4181	0.695	1.053
0.6	61.7	194	4791	0.797	1.035
0.8	82.3	146	5402	0.898	1.018
1.0	102.9	117	6013	1.000	1.000

Table 5 shows the effect of the degree of shear connection on the 24 m building beam. Full connection required 102.9 studs per half span, based on a stud resistance of 69.4 kN, a concrete flange force of 7140 kN and a plastic moment of 6013 kN·m. Reducing η to 0.6 cut the stud number to 61.7, a 40% saving, and lowered moment capacity to 4791 kN·m, or 79.7% of the design moment. Deflection rose by only 3.5% because the unpropped construction factor of 0.3 was applied. Capacity at full connection was 2.03 times that of the steel section alone (2960 kN·m), confirming the value of effective connection.

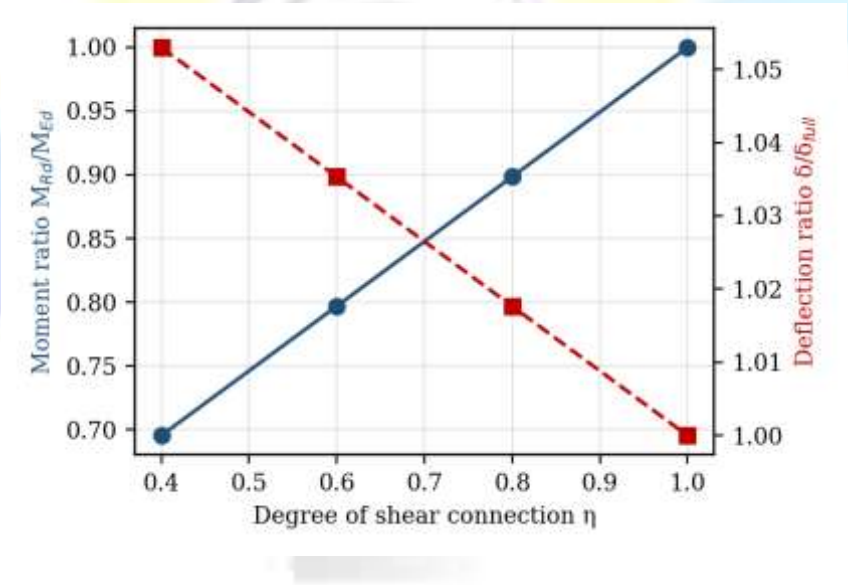


Figure 5: Moment ratio and deflection ratio versus degree of shear connection η (24 m beam).

Figure 5 plots the moment ratio and deflection ratio against the degree of shear connection. The moment ratio (solid line, left axis) increases linearly from 0.695 at η = 0.4 to 1.00 at η = 1.0, reflecting the linear interaction rule. The deflection ratio (dashed line, right axis) declines from 1.053 to 1.000 and is much flatter, showing that stiffness is less sensitive than strength to a reduction in connectors. Because the beam was sized for full connection, any η below 1.0 must be compensated by a larger steel section, so the figure helps designers balance stud cost against steel tonnage [22].

5. DISCUSSION

5.1 Critical Analysis of the Data

The data show that composite action is consistently beneficial but with diminishing returns. The percentage steel saving fell with span in both applications ($R^2 > 0.90$) because the effective slab width is capped by spacing whereas dead load and moment grow with span, so composite construction is most efficient in the 12–30 m range for buildings. Bridge savings are larger, yet they are inflated by the span/800 limit, which penalises bare steel; a looser

criterion would narrow the margin. Slab behaviour diverges sharply: building slabs are governed by shear bond and are highly span sensitive, whereas bridge slabs are governed by local wheel load bending with demand rising steadily with spacing. Partial shear connection offers real economy, but its benefit is conditional on enlarging the steel section. Vibration emerges as the hidden governing limit for long spans in both systems. Composite beams remain shallower, which lowers storey height and cladding cost, but these secondary gains were not quantified here. Finally, the dataset is analytical, uses simply supported spans, and omits fatigue, creep, shrinkage and continuity, so absolute values should be read as comparative indicators rather than design values, and the linear trends should not be extrapolated beyond the ranges studied.

5.2 Comparison with Past Work

The trends agree with earlier work. The linear relationship between connection degree and moment capacity is the rule derived from tests on beams with partial connection and adopted in Eurocode 4 [2], [22], and the small deflection penalty follows the same source. The m–k values used here are of comparable magnitude to those reported for embossed trapezoidal sheeting [19], [20], and the sensitivity of capacity to shear span mirrors the behaviour identified by Porter and Ekberg and by Daniels and Crisinel [15], [17]. The steel saving of roughly one quarter to one third for buildings is of the same order as savings cited in composite design guides [1], [9], although such values depend on the alternative assumed. The decline of percentage saving with span is consistent with the understanding in composite design manuals that the slab contribution is limited by effective width [8], [9]. The frequency trend reflects the classical dependence of beam frequency on stiffness, mass and the square of span, which is why vibration checks are emphasised in guidance for long span floors [1], [10]. The reinforcement demand computed for bridge decks lies in the range normally adopted for slabs on girders, although final detailing must follow IRC provisions [6]. For bridges, the greater benefit agrees with the wide adoption of composite plate girders described by Brozzetti [30]. Earlier finite element studies included slip and nonlinear connector behaviour and therefore predicted deflections more precisely [24], [26], [29]; the present closed-form approach cannot capture these effects, but its advantage is transparency and speed. Unlike most earlier studies, which treat buildings or bridges in isolation, the present comparison places both on a common analytical basis. It also adds regression relationships for steel saving, deck moment and frequency that can support preliminary design. Such validation remains essential before adoption in practice.

6. CONCLUSION

This paper analysed a parametric dataset of steel–concrete composite members to clarify how composite construction performs in long span buildings and bridges, with emphasis on the behaviour of the composite deck slab. Composite action reduced structural steel weight by 22.3–31.7% in building beams of 12–36 m span and by 34.2–55.6% in bridge girders of 20–60 m span, and the saving declined linearly with span in both cases (R^2 = 0.924 and 0.904). Building deck slabs on profiled sheeting were governed by shear bond, with utilisation rising from 0.43 to 1.00 as slab span increased and thickness decreased, whereas bridge deck slabs carried equivalent loads of 26.9–54.4 kN/m² and their design moment grew almost linearly with girder spacing. Partial shear connection of 60% saved 40% of the studs at the cost of a 20% loss of moment capacity and a 3.5% deflection

increase. Fundamental frequencies fell below 3 Hz beyond 12 m in buildings and 20 m in bridges, so vibration should be checked early. These findings confirm the relationships stated in the abstract and show that composite construction is efficient, but that its advantages depend on span, slab type and connection detailing. Future work should validate the dataset against tests and finite element models and should extend it to continuous spans, fatigue, creep, shrinkage and precast deck systems. The five tables and five figures demonstrate that efficient use of composite action depends on matching slab type, girder depth and degree of connection to the span and loading of the structure.

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