Determination of composite slabs resistance by the partial shear connection method considering friction at the support

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Abstract. This paper aims to evaluate the behavior and longitudinal shear strength of the steel-concrete composite slab using the Steel Deck P75 through the partial shear connection method considering the contribution of the friction acting in the interface of the steel deck with the concrete at the region of supports. The method proposed by EN 1994-1-1:2004 for the design of composite slab systems is based in the analytical model similar to that of composite beams which allows to determine the degree shear connection between the steel sheeting and the concrete. This method allows analysis the influence of friction at the support, in addition to the contribution of stud bolts on the mechanical resistance of composite slab. The composite slab was tested in the Federal University of Minas Gerais structure laboratory which used the semi-empirical "*m-k*" method to obtain its resistance. The behavior of the composite slab system was analyses through of the graphics deflections, end slips and strains, allowing the determination of its failure mode. Finally, the results obtained from the longitudinal shear resistance considering the friction at the support were applied in one practical examples.

Keywords: Composite slabs, Partial shear connection, Friction at the support.

1 Introduction

The Partial Shear Connection method (PSC) is based on an analytical model, similar to that of composite beams for ductile connectors, presented by ABNT NBR 8800 [1], which is subsidized by EN 1994-1-1 [2]. This method is applied to calculate the longitudinal shear strength of the composite slab, which allows estimating the resistant bending moment of each cross section of the analyzed specimen. This moment is determined as a function of the ultimate limit state, which is reached due to excessive relative sliding between the steel deck and the concrete, since the two materials, which work connected, lose the ability to transfer stresses from their main mechanisms called embossments. In this sense, according to Bradford [3], it is generally assumed that the chemical bond, friction and the action of embossments are sufficient to fully restrict the relative sliding between steel and concrete, but what happens in reality is a condition of partial connection between these components after the concrete cracking. Additionally, PSC allows the analysis of additional effects on the resistance of the composite slab, such as the influence of friction in the region of the slab supports, which enables an increase in the bearing capacity of the structure. Thus, the application of PSC method considering the influence of friction support will be performed to determine the resistance of the composite slab using Steel Deck P75.

2 Experimental test

According to recommendations in EN 1994-1-1 [2], the proper evaluation of the composite structural system requires a full-scale test, similar to the use of this structure. Thus, the four-point bending test was performed, in which the tested specimens were linked through a "pinned support - hinged support" system, which, in turn, was supported on two concrete blocks. The loading application was performed by a hydraulic actuator, which applied a concentrated load on a steel beam, and this discharged the load on the other two beams symmetrically arranged on the slab. This loading scheme can be seen in Fig. 1.

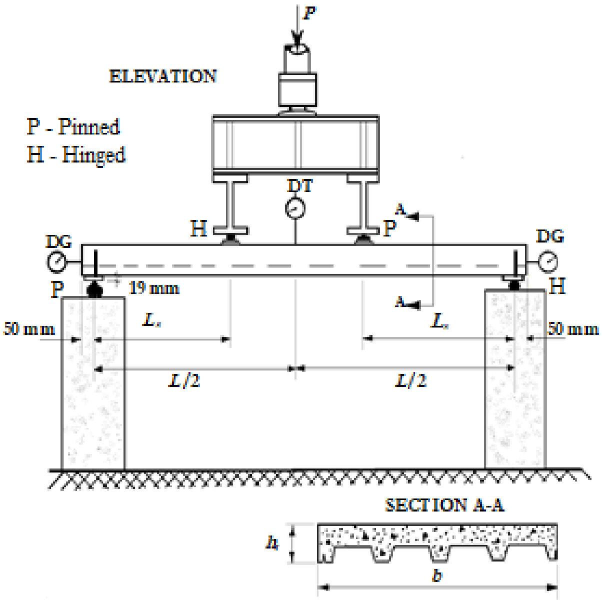

Figure 1. - Typical test set-up

Using this loading condition was performed in 12 composite slab specimens with span (*L*) equal to 2700 mm, 6 specimens with steel deck with thickness (*t*) equal to 0.65 mm, and other 6 specimens with a thickness equal to 0.95 mm. In the tests of these specimens the shear span (L_s) was also varied as presented in Table 1.

Table 1. Steel Deck P75 tested specimens

Specimen	*t* (mm)	L_s (mm)
P75-1A	0.65	450
P75-1B	0.65	450
P75-2A	0.65	650
P75-2B	0.65	650
P75-3A	0.65	900
P75-3B	0.65	900
P75-4A	0.95	450
P75-4B	0.95	450
P75-5A	0.95	650
P75-5B	0.95	650
P75-6A	0.95	900
P75-6B	0.95	900

Using two strain gauges installed on the upper (*EER-upper*) and lower (*EER-lower*) tables of the steel deck, at mid-span of the composite slab, the strains were measured, resulting in the load versus strain graph shown in Fig. 2, using specimen 2A as representative of the others. Vertical displacements (deflections) and relative end displacements were measured by two and four displacement transducers (*DT*) positioned at mid-span of the composite slab and at its ends, respectively. The graphs representing load versus deflection at mid-span and load versus relative end slip are presented in Figs 3 and 4, respectively, using specimen 2A as representative of the others.

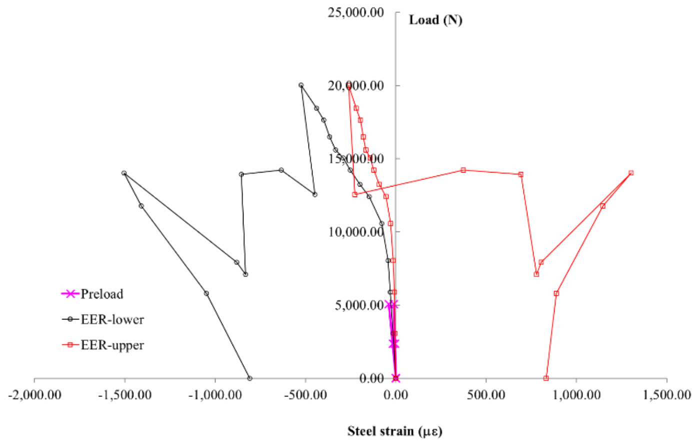

Figure 2. - Load versus steel strain curves for specimen 2A

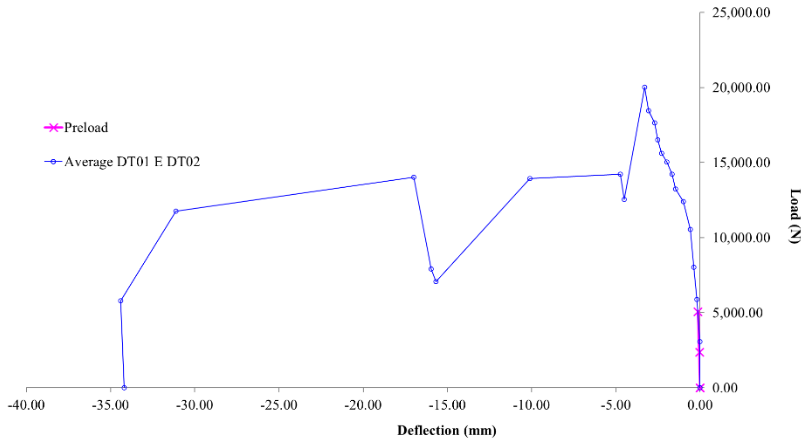

Figure 3. - Load versus midspan deflection of the specimen 2A

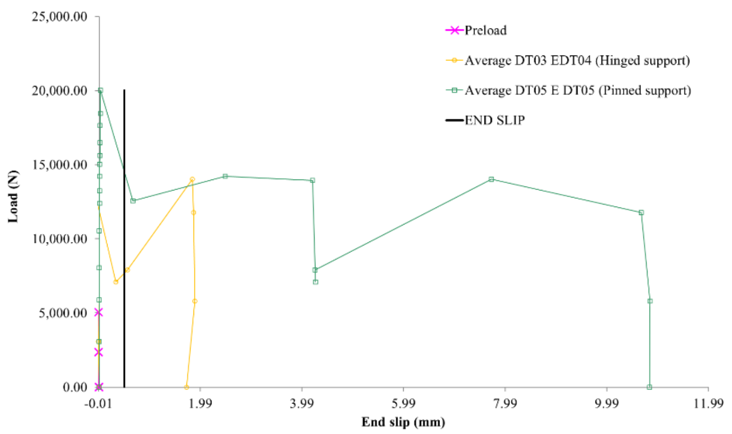

Figure 4. - Load versus end-slip of the specimen 2A

Only one collapse mode was observed for all specimens tested: the collapse by longitudinal shear. The characterization of the collapse by longitudinal shear of the P75 composite slab system is similar to other steel deck systems, as reported in Melo [4], Brendolan [5], Costa [6] and Grossi [7] and other researchers.

3 Partial shear connection method

The application of the Partial Shear Connection method, according to ABNT NBR 8800 [1] and EN 1994-1-1 [2], consists in evaluating the stress distribution in a typical plasticized cross section of the composite slab to obtain the bending moment resistance and determine the ultimate design stress in longitudinal shear ($\tau_{u,Rd}$). To determine the resistance of the composite slab, there are two hypotheses, which are called total and partial interaction between the steel deck and the concrete. The occurrence of each of these cases depends on the ability to transfer stresses between steel and concrete through mechanisms, called embossments, which are stamped in the steel deck. In the case of partial shear connection, there is a relative slip between the steel deck and the concrete, implying the formation of two neutral axes: one in the concrete (LNP_c) and another in the steel sheeting (LNP_f), as illustrated in Fig. 5.

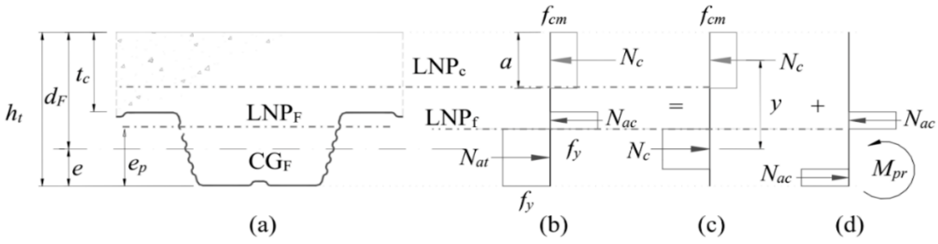

Figure 5. - Normal stress distribution for sagging bending, considering the partial shear connection

From Fig. 5, it is observed that h_t is the total height of the composite slab; d_F is the effective height of the model; LNP_F is the plastic neutral axis of the steel sheeting; CG_F is the center of gravity of the steel deck; e is the distance from the CG_F to the bottom face of the steel deck; e_p is the distance from the LNP_F to the bottom face of the steel sheeting; t_c is the concrete height above the top face of the steel deck; a is the depth of the concrete block in compression; y is the lever arm; N_{at} is the tensile normal force in the steel sheeting; N_c is the compressive normal force in the concrete flange; N_{ac} is the compressive normal force in the steel sheeting.

The resistance of the composite slab is calculated by obtaining the nominal partial bending moment (M_{Rp}), which is obtained by sum of the moment produced by the normal forces (N_c) between the steel deck and the concrete, and the reduced plastic resistance moment (M_{pr}) of the profiled steel sheeting, as shown in eq. (1).

$$M_{Rp} = N_c\, y + M_{pr} \tag{1}$$

where M_{pr} is obtained from eq. (2).

$$M_{pr} = 1{,}25 M_{pa}\left(1 - \frac{N_c}{N_{pa}}\right) \leq M_{pa} \tag{2}$$

The lever arm, y, is determined by eq. (3):

$$y = h_t - 0{,}5a - e_p + \left(e_p - e\right)\frac{N_c}{N_{pa}} \tag{3}$$

The depth, a, of the stress block in compression, is given by eq. (4):

$$a = \frac{N_c}{b\, f_{cm}} \leq t_c \tag{4}$$

The methodology used by EN 1994-1-1 [2] in presenting the Partial Shear Connection method disregards the effect of friction on the supports and leads to conservative results in the calculation of the longitudinal shear resistance. Therefore, through several studies, such as Veljkovic' [8], Tenhovuori [9], Souza Neto [10] and Costa [6, 11], among others, it was found that in steel-concrete composite slabs the influence of friction on the supports is relevant in the calculation of the longitudinal shear resistance.

The influence of friction acting at the interface between steel deck and concrete to determine the longitudinal shear resistance of the composite slab is given by the contribution of the frictional force (F_{at}), determined by eq. (5), and generated due to the reaction at the supports, which acts resisting the shear stress, as illustrated in Fig. 6.

$$F_{at} = \mu\, V_{ut} \tag{5}$$

where μ is the friction coefficient between steel and concrete, V_{ut} is the support reaction obtained in the experimental test.

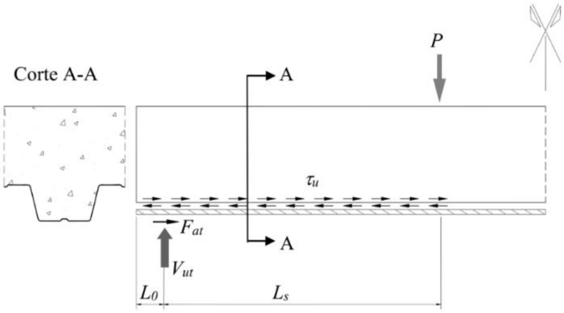

Figure 6. - Friction force in the region of support at the interface of composite slab

The longitudinal shear strength in composite slabs using PSC method considering support friction is obtained from the average ultimate shear stress (τ_u) at the steel-concrete interface provided by the embossments in the steel deck and the support friction, using the following expression:

$$\tau_u = \frac{N_c - \mu\, V_{ut}}{b(L_S + L_O)} \tag{6}$$

where b is the width of the composite slab and L_o is the length of the overhang at the ends of the tested specimen.

According to EN 1994-1-1 [2], the characteristic longitudinal shear strength ($\tau_{u,Rk}$) should be calculated by eq. (7), by means of an appropriate statistical model, in which the values from tests with the 5% quantile are used.

$$\tau_{u,Rk} = \tau_{u,m} - t\, s \tag{7}$$

where $\tau_{u,m}$ is the is the mean value of the longitudinal shear strength of a composite slab determined from testing for each group of steel deck thicknesses, t is the confidence coefficient from Student's Distribution and s is the standard deviation of the longitudinal shear resistances.

The design longitudinal shear strength ($\tau_{u,Rd}$) is expressed by eq. (8), given by:

$$\tau_{u,Rd} = \frac{\tau_{u,Rk}}{\gamma_{sl}} \tag{8}$$

where γ_{sl} is the partial factor for design shear resistance of a composite slab.

By applying the values of N_c in eq. (1) to (4), the design partial interaction diagram is obtained, by which the bending moment resistance is determined as a function of each cross section of the composite slab, as illustrated in Fig. 7, in which it is also possible to observe the minimum length (L_{sf}) for full interaction between steel sheeting and concrete, which can be given by eq. (9).

$$L_{sf} = \frac{N_{cf} - \mu\, V_{l,Rd}}{b\, \tau_{u,Rd}} \tag{9}$$

From the design longitudinal shear strength ($\tau_{u,Rd}$), for each steel deck thickness, the slab compressive force (N_c) can be calculated at any section at a distance L_x from the support (Fig. 7), according to eq. (10).

$$N_c = b\, L_x\, \tau_{u,Rd} + \mu\, V_{l,Rd} \tag{10}$$

where $V_{l,Rd}$ is the design value of the resistance to shear.

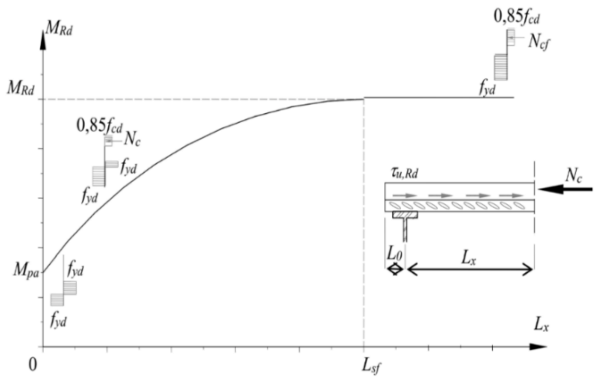

Figure 7. - Design partial interaction diagram

4 Example application

To evaluate the application of the Partial Shear Connection method aiming at the actual design situation considering the friction of support in a composite slab with Steel Deck P75, the maximum uniformly distributed superimposed load (w_{sp}) will be calculated on a slab with width (b) 1,000 mm and span (L) of 2,700 mm (Fig. 8). Figure 9 illustrates the model considering the uniformly distributed loading (w_{sp}) and dead weight load (pp_{slab}) of the structure.

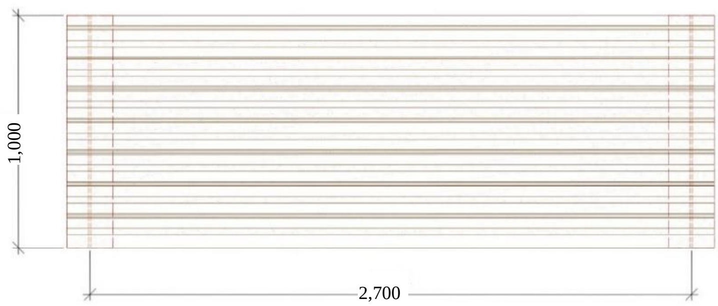

Figure 8. –Plan of the composite slab

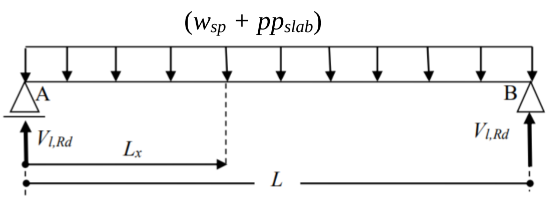

Figure 9. – Uniformly distributed load

The following are the data of the composite slab: t = 0.65 mm; $A_{F,ef}$ = 886.00 mm²/m; $e = e_p$ = 37.19 mm; f_y = 280 MPa; f_{ck} = 20 MPa; h_t = 160 mm; d_F = 122.81 mm; pp_{slab} = 0.00301 N/mm²; μ = 0.50; γ_f = 1.40; γ_{sl} = 1.25; $\tau_{u,Rd}$ = 0.0292 MPa.

Table 2 it is possible to observe the determination of the maximum value of w_{sp} using PSC method considering the support friction. The value of w_{sp} is determined at the intersection point between the design resistant moment (M_{Rd}) and design bending moment (M_{Sd}) curves. Thus, for this case, the maximum uniformly distributed superimposed load supported by the composite slab is equal to 5.386 N/mm² and the minimum length, L_{sf}, for full interaction is equal to 7,226 mm, being outside the interval domain of the structure.

Table 2. Determination of maximum superimposed load (w_{sp})

L_x (mm)	N_c (N)	a (mm)	y (mm)	M_{pr} (Nmm)	M_{Rd} (Nmm)	w_{sp} (kN/m²)	maximum w_{sp} (kN/m²)	M_{Sd} (Nmm)
0	14677	1.21	122.21	4732797	6526384	-		0
50	16136	1.33	122.15	4732797	6703720	69.267		778698
100	17595	1.45	122.09	4732797	6880881	34.797		1528010
150	19054	1.57	122.03	4732797	7057866	23.350		2247938
200	20513	1.69	121.97	4732797	7234677	17.661		2938481
250	21972	1.81	121.91	4732797	7411311	14.276		3599640
300	23431	1.93	121.85	4732797	7587771	12.045		4231413
350	24890	2.05	121.79	4732797	7764055	10.475		4833802
400	26349	2.17	121.73	4732797	7940164	9.319		5406806
450	27808	2.29	121.66	4732797	8116098	8.441		5950425
500	29267	2.41	121.60	4732797	8291856	7.759		6464659
550	30726	2.53	121.54	4732797	8467439	7.219		6949509
600	32186	2.65	121.48	4732797	8642846	6.789		7404973
650	33645	2.77	121.42	4732797	8818079	6.444		7831053
700	35104	2.89	121.36	4732797	8993136	6.167		8227748
750	36563	3.01	121.30	4732797	9168017	5.945		8595058
800	38022	3.13	121.24	4732797	9342724	5.771		8932984
850	39481	3.25	121.18	4732797	9517255	5.636		9241524
900	40940	3.37	121.12	4732797	9691610	5.536	5.386	9520680
950	42399	3.49	121.06	4732797	9865791	5.468		9770451
1000	43858	3.61	121.00	4732797	10039796	5.427		9990837
1100	46776	3.85	120.88	4688971	10343455	5.386		10343455
1200	49694	4.09	120.76	4612424	10613690	5.414		10578533
1300	52612	4.33	120.64	4535876	10883224	5.533		10696073
1350	54071	4.45	120.58	4497602	11017728	5.626		10710765
1400	55531	4.57	120.52	4459328	11152057	5.744		10696073
1500	58449	4.81	120.40	4382781	11420188	6.054		10578533
1600	61367	5.05	120.28	4306233	11687618	6.477		10343455
1700	64285	5.29	120.16	4229685	11954347	7.036		9990837
1800	67203	5.53	120.04	4153137	12220375	7.766		9520680
1900	70121	5.77	119.92	4076590	12485701	8.725		8932984
2000	73039	6.01	119.80	4000042	12750326	10.001		8227748
2200	78875	6.50	119.56	3846946	13277472	14.233		6464659
2400	84712	6.98	119.32	3693851	13801813	24.375		4231413
2600	90548	7.46	119.08	3540756	14323349	75.690		1528010
2700	93466	7.70	118.96	3464208	14583065	-		0

5 Conclusions

The objectives of this paper were to evaluate the behavior and determine the resistance of a steel and concrete composite slab using Steel Deck P75 by applying the Partial Shear Connection method considering at the support friction. Therefore, it was verified, through the evaluation of the behavior of the proposed specimens of the P75 steel and concrete composite slabs, that the collapse was by longitudinal shear. This ultimate limit state is characterized by the failure, by shear, of the connection between the embossments in the steel deck and the concrete, causing the concrete in the region of the shear span to lose its composite action with the steel sheeting. This failure is indicated by an end slip between the steel deck and the concrete at the end of the specimen. Thus, the Partial Shear Connection method was applied to obtain the longitudinal shear strength considering at the support friction. Finally, using this design resistance obtained through the test, a practical example was proposed in which the maximum uniformly distributed superimposed load, w_{sp}, equal to 5,386 kN/m² that the composite slab supports for the suggested span was obtained.

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