SDSS'Rio 2010 STABILITY AND DUCTILITY OF STEEL STRUCTURES
E. Batista, P. Vellasco, L. de Lima (Eds.)
Rio de Janeiro, Brazil, September 8 - 10, 2010

INFLUENCE OF THE FRICTION AT THE SUPPORT IN THE LONGITUDINAL SHEAR STRENGHT OF COMPOSITE SLAB

A. C. C. Lavall*, R. S. Costa * and F. C. Rodrigues**

* Armando Cesar Campos Lavall and Rodrigo Sernizon Costa UFMG
E-mails: lavall@dees.ufmg.br, rsernizon@dees.ufmg.br

** Francisco Carlos Rodrigues UFMG
E-mail: Francisco@dees.ufmg.br

Keywords: composite slabs; partial shear connection method, friction at the support.

***Abstract**. The aim of this work is to evaluate the behavior and strength of composite slabs considering the influence of the friction at the supports. For this, were used the results of a program of laboratory tests carried through in the Structural Engineering Department of UFMG, considering the Steel Deck-60, which consists of trapezoidal profile with embossments in "V" shape. During the tests deflections, end slips and strains of the steel decks were measured, allowing the analysis of the behavior of the composite slab system and the determination of its failure mode. The influence of the friction at the supports in the longitudinal shear bond was evaluated through the partial shear connection method, using the friction coefficient recommended by [1]. Comparative analysis with other methods allow affirming that the influence of the friction at the support in the longitudinal shear bond is significant, mainly, in composite slabs with short shear spans.*

1 INTRODUCTION

Composite slab systems have prevailed as an appropriate method for building slabs. From the standpoint of the structural behavior, the profiled steel sheet shall be capable of transmitting horizontal shear at the interface between the sheet and the concrete. Composite behavior between profiled sheeting and concrete shall be ensured by mechanical interlock provided by embossments, frictional interlock for profiles shaped in a re-entrant form, end anchorage provided by welded studs and friction of the region of the supports. If there is no mechanical link or an attachment by friction between the sheeting and concrete, it will not be able to transmit the longitudinal shear, and thus the composite slab action will not be effective.

The aim of this paper is to present the partial shear connection method considering the influence of friction at the support for determining the additional longitudinal shear resistance of composite slab system *Deck-60*, after curing the concrete. To achieve this goal the results of research carried out by [2] were used.

2 CHARACTERIZATION OF THE SPECIMENS AND TEST PROCEDURE

To develop the analysis by the partial shear connection method considering the friction at the support, a series of twelve specimens of the *Deck-60* with simple support was tested to bending. The models were divided into two groups, six with nominal thickness t = 0.80 mm and six with t = 0.95 mm. The steel deckings of the specimens were made of steel ZAR 280 and ZAR 345 for thicknesses t = 0.80 mm and t = 0.95 mm, respectively, and length L = 2500 mm and nominal width b = 860 mm. In each group three specimens had depth h_t = 110 mm and span shear L_s = 800 mm and the other three specimens had depth

h_t = 140 mm and span shear L_s = 450 mm. Figure 1 show a typical cross-section profile of the *Deck-60* and its nominal dimensions in millimeters. The ‘‘V-shape’’ embossments were pressed onto the webs.

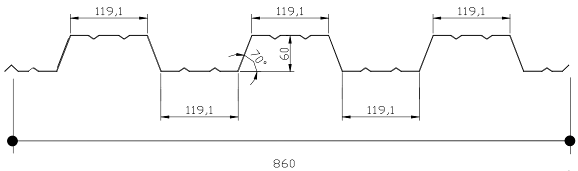

Figure 1 - Typical geometric profile of the *Deck-60*.

The modulus of elasticity of structural steel, E_a, was taken equal to 200 GPa and the characteristic compressive strength of concrete, fck = 20 MPa. Each model was subjected to a symmetrical mode of loading consisting of a two-point concentrated line load arrangement, as shown in Figure 2. This system of load application is similar to those indicated by [1] and [3].

Vertical deflections at the centre of span were measured by means of two 0.01 mm displacement transducers (DT), symmetrically arranged at approximately 20 cm from the edge of the slab. The end-slip between the steel deck and concrete was recorded through two 0.001 mm digital dial gauges (RC), attached at the ends of each specimens, two on each side.

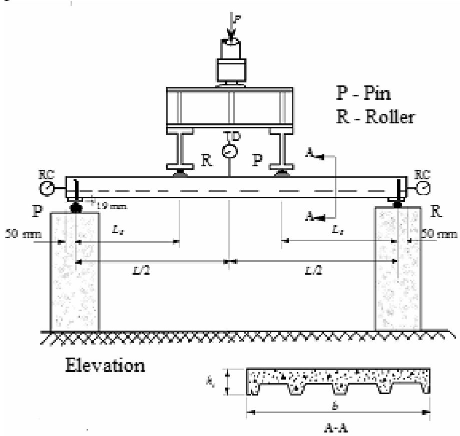

Figure 2 - Typical test set-up arrangement.

Electrical resistance strain gauges (EER) were applied to all of the specimens to ascertain the state of strain in the steel. Loading was applied in increments and each load level was maintained only until the necessary strain, deflection and end-slip readings were recorded. Cracking characteristics, mode of failure, end-slip and ultimate load of each specimen were documented.

3 TEST RESULTS AND ANALYSIS

The analysis of results and a general behavior description of composite slabs are studied by referring to the relationships load versus end-slip, load versus midspan deflection and load versus strain of the steel.

Figure 3 shows the load versus end-slip curves of the specimen 01A. It can be seen that initially horizontal slip is almost zero, occurring a full shear connection between the sheeting and concrete. After the formation of initial cracks, the chemical bond between the sheeting and the concrete is broken causing end-slip, characterizing the partial connection. According to [1] the initial end-slip load (P_{des}) is defined as the load causing an end slip of 0.5 mm between the sheeting and concrete.

Figure 4 shows the load-midspan deflection curve for the specimen 04B, where two stages of load-deflection behavior were identifiable: the uncracked stage and cracked stage. In the first stage no visible cracking was observed anywhere on the specimen, hence, the entire section remained fully composite up to initial cracking.

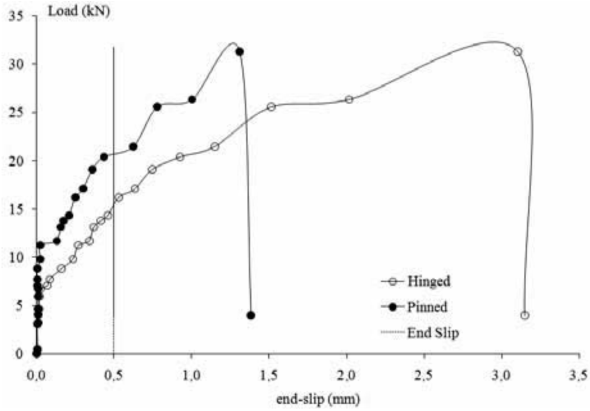

Figure 3 - Load versus end-slip of the specimen 01A

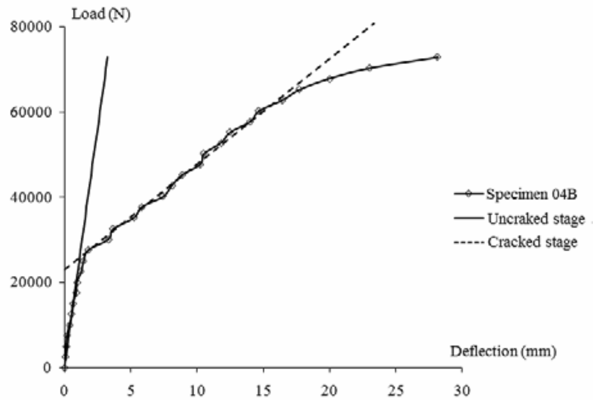

Figure 4 - Load-midspan deflection curve of the specimen 04B

The cracked stage was identified by the first significant change in initial stiffness of each specimen, which occurred with the initial cracking (the load-deflection curve ceases to be linearly proportional). Without the presence of shear transfer devices (embossments and friction) the specimen would not be able to carry any additional load beyond this load stage. According to [1], the load-midspan deflection curves allow to classify the longitudinal shear behavior of the composite slab system as ductile, since the failure load exceeded the initial end-slip load (P_{des}) by more than 10%.

Figure 5 shows the load versus strain of the steel curve for the specimen 01A, where negative values indicate tensile strain. During the uncracked stage occurs a linearly proportional increase of the tensile strain in the sheeting in both, the lower and higher fibres, indicating the existence of a single neutral axis in the concrete. The tensile strain of the top of the sheeting decreases after the initial cracking indicating the presence of two neutral axes in the composite section, characterizing the partial shear connection between the sheeting and concrete.

Based on the experimental results of this investigation, only one mode of failure was experienced with the *Deck-60* composite slab system, namely, longitudinal shear (shear bond). This behavior has been observed by [3], [4], [5] and other authors.

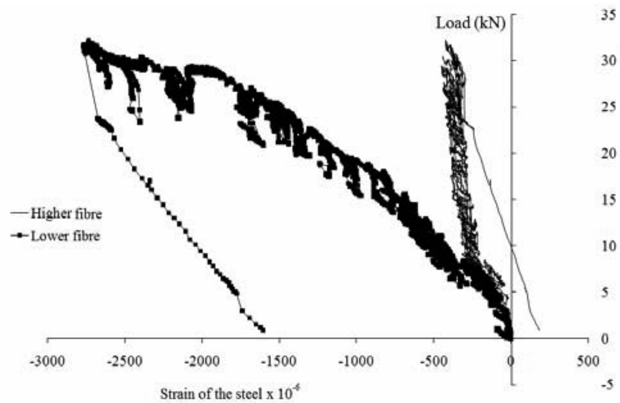

Figure 5 - Load versus strain of the steel of the specimen 01A

4 PARTIAL SHEAR CONNECTION METHOD

According to [1] two methods are used for the design of composite slabs: the *m-k* method and the Partial Shear Connection (*PSC*) method. Both methods are based on the results of full-scale experiments. Depending on the test results the behavior of a slab is classified as brittle or ductile. The *m-k* method may be used for all profiles, while the *PSC* method may be used only for ductile profiles. In addition, the *PSC* allows evaluating theoretically the contribution of the end anchorage and of the friction at the support in the longitudinal shear strength.

4.1 Analytical model

The *PSC* method is based on an analytical model with a physical background, as illustrated in figure 6. The model can be better understood by examining the typical module of the composite slab as shown in figure 6a. The normal stress distribution considering the partial interaction has two neutral axis: one in concrete (LNP_c) and other in the sheeting (LNP_f), as shown in Figure 6b. This distribution can be decomposed, by simplification, in the diagrams shown in the figures 6c and 6d.

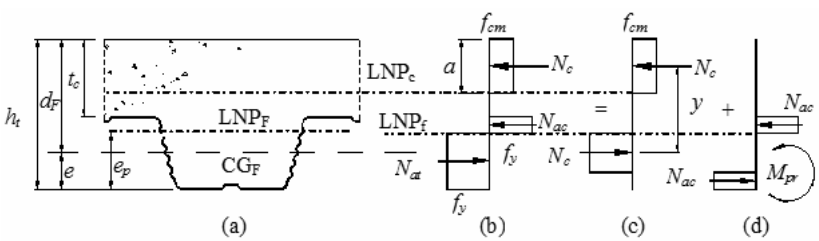

Figure 6 – Normal stress distribution for sagging bending considering the partial interaction

Where h_t is the overall depth of the slab; e is the distance from the centroidal axis of profiled steel sheeting to the extreme fibre of the composite slab in tension; d_F is the distance between the centroidal axis of the profiled steel sheeting and the extreme fibre of the composite slab in compression; e_p is the distance from the plastic neutral axis of profiled steel sheeting to the extreme fibre of the composite slab in tension; t_c is the thickness of concrete above the main flat surface of the top of the ribs of the sheeting;

f_y is the actual value of the yield strength of structural steel, obtained from specific tests, where f_y = 340 MPa and 390 MPa for thicknesses t = 0.80 mm and t = 0.95 mm, respectively; f_{cm} is the mean value of the compressive strength of concrete, obtained from specific tests, where f_{cm} = 24.9 MPa and 22.2 MPa for thicknesses t = 0.80mm and t = 0.95 mm, respectively; a is the depth of the concrete block in compression; y is the lever arm in the slab; N_c is the compressive normal force in the concrete flange; N_{ac} is the compressive normal force in the sheeting; N_{at} is the tensile normal force of in the sheeting.

The bending resistance is given by:

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

where M_{pr} is the reduced plastic resistance moment of the profiled steel sheeting, due to the presence of the tensile normal force in the sheeting, $N_a = N_c$.

4.2 Determination of longitudinal shear resistance considering the friction at the support

In recent studies, as [4], [7], [8] and [9], among others, it has been observed that in models with relatively short shear spans the influence of the friction at the supports is relevant in determining of the longitudinal shear resistance, while for long shear spans this effect is reduced.

To determine the longitudinal shear strength, the partial interaction diagram of each specimen, as shown in figure 7, should be determined using the measured dimensions and strengths of the concrete and the steel sheet.

From the maximum applied loads, the bending moment (M_{test}) at the cross-section under the point load due to the applied load, dead weight of the slab and spreader beams should be determined and then divided by the bending moment resistance of the slab considering the full connection, M_R. The path A $\Rightarrow$ B $\Rightarrow$ C in figure 7, gives the degree of shear connection, $\eta_{test} = N_c/N_{cf}$ for each specimen, where N_{cf} is the value of the compressive normal force in the concrete with full shear connection.

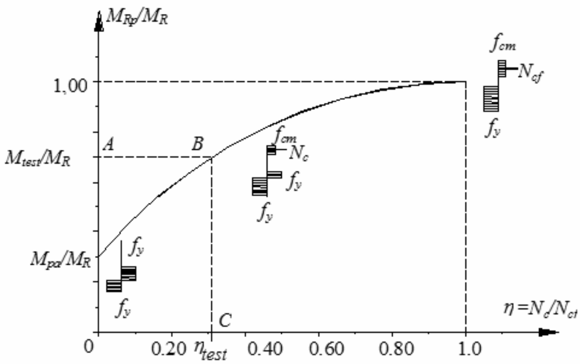

Figure 7 - Determination of the degree of shear connection from M_{test}

After determining the value of η_{test}, the compressive normal force in the concrete, N_c, is given by:

$$N_c = \eta_{test} \; N_{cf} \tag{2}$$

The value of the longitudinal shear strength of a composite slab, τ_u, considering the friction at the support for each specimen is assumed uniform along the length (L_s + L_0) and its value is determined by the following equation:

$$\tau_u = \frac{N_c - \mu V_{ut}}{b(L_s + L_o)} \tag{3}$$

where V_{ut} is the support reaction, L_0 is the length of overhang (L_0 = 50 mm).

According to [1] characteristic value of longitudinal shear strength, $\tau_{u,Rk}$, should be calculated as the 5% fractile by using an appropriate statistical model, in accordance with [10], Annex D. In this work the Student's distribution was adopted:

$$\tau_{u,Rk} = \tau_{u,m} - t\,s \tag{4}$$

where $\tau_{u,m}$ is the mean longitudinal shear strength resulting from the tests; t is the reliability coefficient of Student's distribution; s is the standard deviation of the longitudinal shear strength.

In table 1 the characteristics values of longitudinal shear strength ($\tau_{u,Rk}$), are determined according to Equation 4. In this table are shown: the degree of shear connection of each specimen tested (η_{test}); the value of the compressive normal force in the concrete (N_c), given by Equation 2, where the values of N_{cf} were calculated by the expression $N_{cf} = N_{pa} = A_{F,\mathrm{ef}}\, f_y$, using the net thickness of the steel decking; the friction coefficient μ = 0.50, adopted in accordance with [1]; the support reactions (V_{ut}) obtained in the tests; the longitudinal shear strength (τ_u) for each tested specimen given by Equation 3; $\tau_{u,m}$ for each thickness of the deck tested and standard deviation (s). The reliability coefficient of Student's distribution $t_{0.95}$ = 2.015 was adopted.

Table 1 - Determination of the characteristic value of longitudinal shear strength ($\tau_{u,Rk}$)

Specimens	η_{test}	N_c (N)	μ	V_{ut} (N)	τ_u (MPa)	$\tau_{u,m}$ (MPa)	s	$\tau_{u,Rk}$ (MPa)
01A	0.592	183474	0.50	20109	0.2383	0.2407	0.0177	0.2050
01B	0.619	191904		20873	0.2503			
01C	0.604	187237		20385	0.2430			
02A	0.357	110716		33405	0.2179			
02B	0.344	106713		32959	0.2100			
02C	0.396	122687		36534	0.2434			
03A	0.528	224689		23864	0.2910	0.2696	0.0214	0.2265
03B	0.488	207877		23975	0.2677			
03C	0.456	194042		22399	0.2507			
04A	0.298	126809		39066	0.2485			
04B	0.322	137110		40511	0.2715			
04C	0.355	151122		43586	0.3015			

The design value of longitudinal shear strength of a composite slab, $\tau_{u,Rd}$, is given by:

$$\tau_{u,Rd} = \frac{\tau_{u,Rk}}{\gamma_{sl}} \tag{5}$$

where γ_{sl} is the partial factor for design shear resistance of a composite slab. The [1] recommends that the value obtained by calculating the coefficient for the design service load (V_s) do not exceed the initial slip load (V_{des}) obtained in the test divided by 1.2. The value of γ_{sl} determined for this system was equal to 1.60.

4.3 Comparative analysis

Figures 8 and 9 are presented in order to compare the results of the nominal shear resistance obtained in the tests with the characteristic shear resistance obtained by the *"m-k"* method and *PSC* method with friction and frictionless, studied by [11].

Analyzing the figures 8 and 9 with thickness of 0.80 mm and 0.95 mm, respectively, it can be observed excellent correlations between the resistances determined by all methods and the results of the tests. For long shear spans, the results obtained by all methods are similar, concluding that in these situations, the influence of the friction at the support in the longitudinal shear resistance is small. Otherwise, for short shear spans, it was observed that the results of the *PSC* method, that explicitly considers the influence of the friction, have a better approximation with the test results. So it can be concluded that for short shear spans the influence of the friction is significant for determining the longitudinal shear strength of composite slabs.

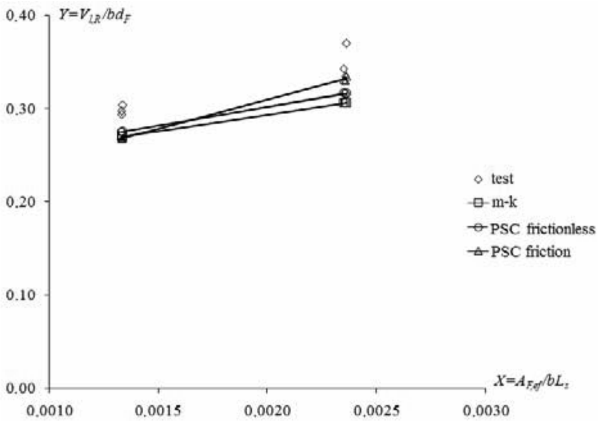

Figure 8 -Characteristic shear resistance of specimens of the groups 01 and 02 (t = 0.80 mm)

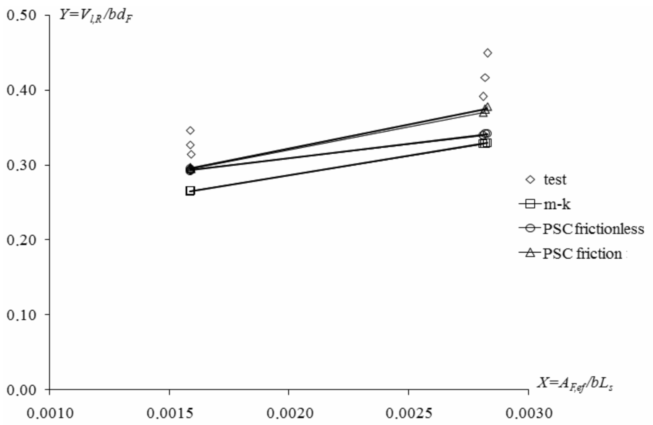

Figure 9 - Characteristic shear resistance of specimens of the groups 03 and 04 (t = 0.95 mm)

5 CONCLUSIONS

Partial shear connection method (*PSC*) is an alternative method to *"m-k"* for checking the longitudinal shear strength that allows evaluating theoretically the contribution of the end anchorage and the friction at the support in the longitudinal shear strength.

The [1] recommends that the partial factor for design shear (γ_{sl}) is equal to 1.25 for the *"m-k"* and *PSC* methods. However, it is recommended that the value obtained by calculating the coefficient for the design service load do not exceed the initial slip load, obtained from the tests, divided by 1.2. So for the *Deck-60* system, γ_{sl} was found equal to 1.60 by *PSC* method considering the influence of the friction at the support, showing that γ_{s1} should be carefully evaluated.

Analysis of results showed that the *PSC* method considering the influence of friction at the support is efficient in the determination of the longitudinal shear resistance showing excellent correlation with test results. It was also observed that the influence of the friction at the support in the longitudinal shear resistance for long shear spans is small, while for short shear spans, the influence of the friction is significant for determining the longitudinal shear strength of composite slabs.

ACKNOWLEDGMENTS

The authors are grateful to CNPq – Conselho Nacional de Desenvolvimento Científico e Tecnológico, for their support to carry out this research.

REFERENCES

EN 1994-1-1, Design of Composite Steel and Concrete Structures, Part 1.1, General rules and rules for building, CEN - European Committee for Standardization, 2004.

Rodrigues F. C. & Lavall A. C. C., Estudo do comportamento estrutural do sistema de laje mista DECK-60/USIMINAS. Relatório técnico, 2005.

Schuster, R. M., Strength and Behaviour of the P-2430 - 12HB, Composite Slab System (normal weight concrete), *Report no. WRI 110-12-02*, Canada: Department of Civil Engineering, University of Waterloo, 1984.

Melo, C. B. F., Análise do Comportamento e da Resistência do Sistema de Lajes Mistas. 141 p. Dissertação de Mestrado, Programa de Pós-Graduação em Engenharia de Estruturas, Universidade Federal de Minas Gerais, Belo Horizonte, 1999.

Araujo, G. S., Análise do Comportamento e da Resistência de um Sistema de Lajes Mistas pelo Método da Interação Parcial. 116p. Dissertação de Mestrado, Programa de Pós-Graduação em Engenharia de Estruturas, Universidade Federal de Minas Gerais, Belo Horizonte, 2008.

Johnson, R. P., Composite Structures of Steel and Concrete - Beams, Slabs, Columns and Frames for Buildings, vol. 01, *Blackwell Scientific Publications*, 2ª edição, Oxford, 1994.

Veljkovic', M., Development of a New Sheeting Profile for Composite Floor. Experimental Study and Interpretation - *Research Report*, Division of Steel Structures, Luleå University of Technology, Tuleå, Swedish, 1993.

Tenhovuori, A., ASCE, Parameters and Definitions for Classifying the Behaviour of Composite Slabs, Composite Construction in Steel and Concrete III, Proceedings of an Engineering Foundation Conference, New York: *American Society of Civil Engineers*, 1996.

Souza Neto A. S., Análise do Comportamento e da Resistência de um Sistema de Lajes Mistas com ancoragem de extremidade com considerações sobre a fôrma de aço isolada e o atrito nos apoios, Dissertação de Mestrado, Programa de Pós-Graduação em Engenharia de Estruturas, Belo Horizonte: Universidade Federal de Minas Gerais, 2001.

EN 1990, Basic Structural Design. CEN - European Committee for Standardization, 2002

Costa, R. S., Análise de um Sistema de Lajes Mistas considerando a Influência do Atrito dos Apoios e a Avaliação do Momento de Inércia Efetivo. 193p. Dissertação de Mestrado, Programa de Pós-Graduação em Engenharia de Estruturas, Universidade Federal de Minas Gerais, Belo Horizonte, 2009.